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**Lifecycle analysis and comparison of different vehicle technologies
in the New Zealand context:
Policy and planning implications**

A Dissertation
submitted in partial fulfilment
of the requirements for the Degree of
Master of Planning

at
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by
Ruby Kimber

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Abstract of a Dissertation submitted in partial fulfilment of the
requirements for the Degree of Master of Planning.

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New Zealand context: Policy and planning implications

by

Ruby Kimber

Over 90% of personal travel in New Zealand is carried out by private vehicles (MoT, 2024b). As a result of this everyday reliance upon private vehicle transit, nationwide planning and policy initiatives in favour of electric vehicles (EVs) have emerged as a more environmentally friendly alternative to traditional internal combustion engine vehicles (ICEs) and a way to accelerate the fulfilment of New Zealand's emissions reduction targets and climate goals. However, these policies are not consistent or long term, facing disestablishment, complete reformation or even replacement. This unsteady course of policy gives rise to the need for consistent, facts-based vehicular incentivisation and legislation that has the opportunity to be long-standing and thereby produce larger, more widespread environment gains.. A lifecycle analysis approach provides a way to uncover this information and address this issue. Effects generated from all phases of a vehicle lifecycle, not just simply operations-based emissions, are critical to the effects generated on the environment, and are yet commonly omitted in current policy and fleet regulations. New Zealand is in need of a nationwide, legislative, solidified understanding as to what vehicle type is the best for emissions reduction through private vehicle ownership and operation, alongside consistent policy and planning mechanisms to reflect this direction.

This research investigation utilizes a two-step methodology approach. Results pertaining to the overall total lifecycle emissions contributions as well as emissions associated with each phase of the vehicle lifecycle were calculated through the usage of an established LCA tool. The results generated are then manually refined based on New Zealand-specific data, including average vehicle lifetime distance, purchased energy emissions factors, and electricity consumption rate or EV 'fuel economy' to make these results bespoke to the New Zealand context.

Findings include the determination of electric vehicles as the best option of light vehicle for emissions reduction within New Zealand. From a total lifecycle emissions perspective, EVs of all sizes and battery range capacities, specifically smaller-sized EVs, prove to contribute less emissions than that of any corresponding ICE. Moreover, replacing the battery in these smaller-sized EVs when required will further enhance the emissions-efficiency by not only extending the lifecycle but also through choosing to add a minimal number of additional emissions as an alternative to opting for manufacture and procurement of an entirely new vehicle unit. In addition, the optimal two-car household combination for the lowest total life cycle emissions contributions would be that of either one small EV that travels frequently accompanied by one large EV that travels only occasionally, or one small EV that travels frequently accompanied by one large ICE that travels only occasionally. Core recommendations to New Zealand vehicular planning and policy are (1) focused incentivization of smaller-sized EVs, (2) increased prioritized subsidy rewards to those with high mileage vehicles, and (3) the inclusion of EV battery replacement within incentivization policies.

Keywords: Electric vehicle (EV), Internal combustion engine (ICE), Life cycle, analysis (LCA), transport policy, planning, emissions reduction, vehicle ownership,

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“I would have to put in the necessary time, but nothing could stop me from succeeding.

We all have a right to our crazy dreams.”

Soichiro Honda
(1906-1991)
Founder of Honda Motor Co., Ltd.

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List of Abbreviations

LCA	Lifecycle assessment
ICE	Internal combustion engine
BEV	Battery electric vehicle
NZ	New Zealand/Aotearoa
GHG	Greenhouse gas
CO ₂	Carbon dioxide
RUC	Road user charges
IEA	International Energy Agency
AFLEET	Alternative Life-Cycle Environmental and Economic Transportation Tool
SUV	Sport utility vehicle
TCO	Total cost of ownership
V2G	Vehicle-to-grid
WOF	Warrant of fitness
MoT	Ministry of Transport
NZTA	New Zealand Transport Agency Waka Kotahi

Definitions

Well-to-Tank	Energy production phase of the vehicle lifecycle (oil refinement and delivery – ICEs, electricity charging – EVs)
Tank-to-Wheel	Fuel combustion phase of vehicle lifecycle (ICEs)

List of Units of Measurement

kg	Kilogram
km	Kilometre
km/day	Kilometres per day
l/100km	Litres per 100km
kWh/100km	Kilowatt-hours per 100km
CO _{2-e} /kWh	Carbon dioxide equivalent per kilowatt-hour of electricity (emissions factor for purchased energy)
kgCO _{2-e}	Kilograms of carbon dioxide equivalent
tCO _{2-eq} /vehicle	Tonnes of carbon dioxide equivalent (used to measure lifetime emissions of vehicle)

Chapter 1

Introduction

1.0 Setting the scene

New Zealand is a country that relies heavily upon private automobile transportation. Between 2023 and 2024, New Zealanders, as a grand total including all modes of transportation, travelled 5.8 million trip legs each year (Ministry of Transport, 2024b). 3.4 million of these trip legs, or approximately 59% of the overall total, was undertaken solely by a privately owned light vehicle (Ministry of Transport, 2024b). Moreover, out of the 54,362 million kilometres travelled by New Zealanders between the year 2023 and 2024, 48,304 million km, or 89%, was travelled via car (MoT, 2024b). This led to national urban and regional planning that caters to car-centric travel more so than other forms of mobility, such as public transport, cycling, and walking. An example of this dominance over other modes of transportation can be found within the recent Government Policy Statement on Land Transport 2024 (Draft), where upper end funding for years 2024-2025 saw \$1,950 million dedicated to state highway improvements, with a lesser \$680 million given to public transport improvements and only \$250 million to walking and cycling improvements (New Zealand Government, 2024, p. 25-28). Consequently, the transportation sector is responsible for approximately 20% of New Zealand's total GHG emissions, and thereby one of the country's highest drivers of climate change (Ministry of Transport, 2025).

As a result of this everyday reliance upon private vehicles, nationwide planning and policy initiatives in favour of electric vehicles (EVs) have emerged, as a more environmentally friendly alternative to traditional internal combustion engine vehicles (ICEs), to accelerate the fulfilment of New Zealand's emissions reduction targets and climate goals (Ministry for the Environment, 2024, p. 10). Prime examples of this include the 2021-2023 Clean Car Discount, where EV purchasers received financial aid towards the initial cost of their EV (Ministry of Transport, 2025). In addition, a long-standing policy involved EVs qualifying for a temporary exemption from road user charges up until April 2024 (NZTA, 2025a). However, these policies, alongside various other approaches (see section 2.2.1), were only in place for a limited time, each facing disestablishment, complete reformation or even replacement. This unsteady course of policy gives rise for the need for consistent, facts-based vehicular incentivisation and legislation that has the opportunity to be long-standing and thereby produce greater and sustained emissions reduction.

The recognition of wider emissions effects contributes to the need for critical analysis and deeper understanding into the true impacts of EV uptake in a society with a very high dependence upon

privately owned vehicular mobility. Solely focusing on the operations-based emissions benefits may lead to a false sense of the true impact of EVs and potentially inaccurately inform global climate mitigation initiatives. Whilst it is expected that driving-based emissions would become the focus for policy, acknowledgement of the emissions pertaining to other areas of the vehicle lifecycle are also important in order to understand the actual, life-long emissions associated with each vehicle type, hence the need for a holistic environmental assessment such as [OBJ:OBJ]. [OBJ] It is also important to recognize [OBJ:OBJ].

Gaps in existing research point to the need to understand the environmental impacts of each vehicle type throughout each stage of its lifecycle (LCA). This includes taking a cradle-to-grave perspective that considers manufacturing, fuel or energy generation, and vehicle operation. Moreover, the inclusion recycling, which holds particular relevance to EVs when considering the battery replacement options available, expands the LCA, and even the vehicle lifespan, into a cradle-to-cradle perspective (Hall & Lutsey, 2018, p. 7). In contrast to a cradle-to-grave lifespan, a cradle-to-cradle perspective refers to a product exhibiting a renewable lifecycle. When an EV receives a replacement battery, the operational phase of the vehicle's lifecycle is extended, adding length to lifecycle phases and additional impacts to consider, therefore continuing and deferring, or even omitting, the end-of-life phase of a cradle-to-grave scope LCA.

Effects generating from other phases of the lifecycle, not just simply operations-based emissions, are critical to the effects generated on the environment, and are yet commonly omitted in current policy and fleet regulations, hence the leading motivation for this research. This research aims to critically analyse and provide information surrounding the environmental impacts of each vehicle type from a holistic approach, as it is important to understand the true impacts of such transitions so that the best outcome is achieved for climate mitigation through the entrenched presence of private passenger vehicles in Aotearoa New Zealand.

1.1 Research objectives/questions

The first research question is:

What vehicle type and/or size shows the lowest projected lifecycle emissions?

- What are the other emissions contributions impacts seen beyond the operation (tank-to-wheel) phase?
- How are the lifecycle emissions, and overall vehicle lifespan, of EVs impacted when considering a cradle-to-cradle lifecycle?

- How do the GHG emissions compare for each stage of the vehicle lifecycle and how does this impact the overall lifecycle emissions of different vehicle types?

The second research question is:

How do the ways in which New Zealand drivers use their vehicles effect the lifecycle emissions impacts and emissions reduction capabilities of different vehicle types?

- What vehicle type combinations are best suited to the typical two-car New Zealand household for optimal emissions reduction results?
- What is the role of EV lifecycle emissions payback point upon lifecycle emissions?

The third research question is:

What changes should be made to current and future New Zealand policy and planning in order to maximise emission reductions from the private vehicle fleet?

1.2 Dissertation roadmap

This dissertation begins with establishing the necessary definitions, conceptualization, and other crucial foundations for understanding, before then progressing into the research's own unique LCA study, and then finally ending with analysis and conclusions that summarize the document as a whole. Specifically, background information defining LCA and its application to this research is detailed in Chapter 2 , in addition to an outline of the current New Zealand vehicular emissions reduction policy landscape also being provided, as well as case study examples of international policy with similar agenda. Following this, Chapter 3 contains the a literature review summarizing the findings, methodologies, limitations, and successes of pre-existing studies is undertaken, including assessment of themes of greenhouse gas emissions, driver behaviour, recycling and battery replacement, and New Zealand-based LCA evident across academic publications within the field. Alongside a review of the pre-existing literature, assessment of established LCA tools is conducted, leading to the selection of one application used to conduct this research.

In Chapter 4 the methodology of this lifecycle calculations-based study is explained in full, including data collection of New Zealand-specific statistics and the process of running the tool. Results are then presented in Chapter 5, considering a the cradle-to-grave forms of total lifecycle emissions per vehicle type and size, emissions per lifecycle phase per vehicle type and size, and lifecycle emissions

of EVs with battery replacement, or from a cradle-to-cradle perspective. The first and second research questions, in relation to best vehicle type and/or size for emissions reduction and the role of driver behaviours and household vehicle combinations in LCA, are then answered using these results.

Chapter 6 discusses the similarities of this study, its methods, and its findings to that of other vehicle type emissions reduction LCA publications, including a description of its uniqueness in comparison to pre-existing vehicle type LCA literature. To answer the third and final research question, implications and recommendations for New Zealand policy and planning are made based on the results generated in this study. Finally, the dissertation ends with a conclusion in Chapter 7, summarizing the key findings and points within this research investigation, and highlights areas for improvement, such as limitations and assumptions made within the study, in addition to lifecycle impact areas for future work and continued analysis.

Chapter 2

Background

2.0 Overview

This chapter includes definition and application of the fundamental environmental planning concept of lifecycle impact assessment, accompanied by an outline of the policy landscape behind vehicle type emissions reduction initiatives in New Zealand at this current time. It identifies and defines such foundational information and thereby clarifies the reasons for this research, and the questions raised within these objectives, contextually.

2.1 Lifecycle impact assessment (LCA)

The following section details the concept of lifecycle impact analysis, or LCA. Firstly, a widespread definition for LCA in environmental management and planning is provided, followed by a discussion surrounding the relevance of this concept to vehicle type LCA comparison, as used by this research investigation.

2.1.1 Definition of Lifecycle impact assessment

According to the Life Cycle Association of New Zealand, LCA “is an analytical tool for the systematic and quantitative evaluation of the environmental impacts of a product or service system through all stages of its life” (LCANA, 2019). This is based on the environmental management concept of “Life Cycle Thinking”, where the impacts of a product or process upon the environment is considered holistically, taking into account all possible areas of effect and all life cycle impact phases present (LCANA, 2019). It is based on the idea that no impact or effect is perceived in isolation to the rest, with all life cycle stages, from manufacturing to disposal and all other stages in-between, equating to the total environmental footprint of the commodity or activity in question (LCANA, 2019).

Beyond a theory-based description, LCA consists of a standardized, methodological, hand-book style set of measures intended to be applied to a situation, process, or product in order to identify and analyze the current or prospective environmental impacts associated. This procedure is known as the ‘ISO 14040 Environmental management life cycle assessment principles and framework’ and it is used universally to conduct all LCAs across the globe (Finkbeiner et al., 2006, p. 81). This ensures that the standards for undertaking a life cycle assessment are consistent no matter the contextual circumstances, warranting the same level of consideration for all areas and the levels of impact associated (Finkbeiner et al., 2006, p. 80-81). These ISO standards have been subject to scrutinization over the years, with ‘ISO 14040’ standing as the defining resource for LCA understanding and

application, and previous versions, including 'ISO 14041', compiling to form the more specialized, scientific procedures reserved for the understanding of LCA professionals, but yet still inform that of the more universal, widespread 'ISO 14040 Environmental management life cycle assessment principles and framework' (Finkbeiner et al., 2006, p. 81-82).

2.1.2 Lifecycle impact assessment and this research

Considering the standardized nature of LCA, it is the ideal, logical methodology choice for vehicle type life cycle assessment and comparison. The universal regulations set out within 'ISO 14040' and 'ISO 14044' ensure that the same level and criteria of assessment is applied to each vehicle type in a way that is uniform and avoids any bias. Secondly, the life cycle assessment of vehicle types in the pre-existing literature, as well as the objectives of this research, contain results expressed in numerical units of measurements, for instance t of CO₂-eq/vehicle. This applies perfectly to the usage of established LCA calculator tools and allow for the calculation of multiple vehicle types and sizes based on varying contextual inputs, such as regional energy systems, distance travelled per day, and vehicle lifespan. Moreover, the all-encompassing perspective of LCA, where all stages of the vehicle's life cycle from beginning to end are accounted for (LCANZ, 2019), means that it is ideal for such research where the recognition and analysis of all life cycle phases is crucial to understanding the true impacts of different vehicle powertrains and masses upon emissions reduction.

That said, LCA is applied to this research through the core methodology choice of LCA calculations through the utilization of a registered, standards-based tool (see section 4.0). The selected tool for the generation of results, alongside general analysis and discussion involved within this study, are based around 'Life Cycle Thinking' processes, taking into consideration all areas of CO₂ emissions impact and their effects (LCANZ, 2019). This also ensures a uniformity to the approach, providing an equal criteria of assessment for all vehicle types and sizes involved within the study to ensure the most accurate results. On a similar note, LCA, with its holistic viewpoint, allows this study to extend the scope for vehicle type analysis from cradle-to-grave to cradle-to-cradle (see section 1.0), accounting for the replacement of EV batteries, thereby providing further in-depth and unique discussion concerning policy and planning recommendations. LCA is equipped to perform vehicle type comparison from both perspectives, and allows for analysis involving additional vehicle life cycle phases, such as battery replacement or recycling, varying lifespan value inputs as a result of vehicle life extension through battery replacement, and how these impact the overall life cycle emissions of each vehicle type and their stance within emissions reduction targets.

2.2 Policy context

To provide insight into the current legislative landscape, the following section details core vehicular policy and planning initiatives for emissions reduction on both a domestic and international scale. This section seeks to place New Zealand in a position of comparison to that of outside vehicular policy for privately-owned vehicle standards and planning-based mechanisms for emissions reduction. Furthermore, by discussing the two contexts of domestic and abroad, leading international case studies have the potential to serve as examples for consistent, fixed policy, which stands as a core objective behind this research investigation.

2.2.1 New Zealand

New Zealand-based vehicle policy, ranging from 2007-2024, portrays a timeline of various government strategies and schemes where change in goals and even tactics for reaching these policy-driven aims frequently experience disestablishment or revoaction. These programmes include vehicle scrappage trials, including the recent Clean Car Upgrade, the Land Transport (Clean Vehicle Standard) Regulations, the Clean Car Discount rebate, and the accompanying exemption of road user charge for EVs.

2.2.1.1 Vehicle scrappage schemes

New Zealand's first vehicle scrappage schemes took place between the years 2007 and 2009, situated in core cities across the country including Auckland, Wellington, and Christchurch (MoT, n.d.). From May to June of 2007, the Ministry of Transport enacted the country's very own car retirement scheme (MoT, 2008, p. 3) in response to the success of international vehicle scrappage schemes happening at this time (see section 2.2.2.3 below). With this being the first programme of its kind in New Zealand (MoT, 2008, p. 3), the goal was to assess the willingness of public participation within such a scheme and to measure the level of success achieved through such a mechanism to determine whether this type of vehicular policy should be continued and improved for future usage (MoT, 2008, p. 3-4). The scheme involved paying New Zealand vehicle owners with a public transportation pass, including access to both train and bus system modes, in exchange for the obtaining and scrappage of their older model vehicle (MoT, 2008, p. 3). The eligibility criteria for a 'scrapable' vehicle revolved around its ability to pass a warrant of fitness (WOF), with vehicles that failed a WOF due to requiring multiple repairs in order to pass being qualified candidates for the trade-in (MoT, 2008, p. 3).

In the end, the pilot scheme was only active for approximately one month, scrapping a grand total of 253 vehicles within this short time frame (MoT, 2008, p. 5). Recorded characteristics of the 253 vehicles scrapped included an average lifespan of 19 years, and an average lifetime travel distance of

195,000km (MoT, 2008, p. 5). By providing this option to the people of Auckland, the Ministry of Transport anticipated the prospective benefits of increased public transport uptake as a result of people trading their vehicle for a bus and railway pass, whilst simultaneously decreasing the number of older, less emissions-efficient ICE vehicles on the road (MoT, 2008, p. 3). Both of these outcomes were sought after due to the contribution they were expected to have towards light vehicle-based emissions reduction through the removal of these vehicles and the incentivization of a more emissions-friendly alternative (MoT, 2008, p. 3). The Ministry of Transport felt that this total figure of 253 vehicles, whilst not significantly positive, was adequate enough to pursue a second vehicle scrappage attempt elsewhere, leading to the second vehicle retirement programme two years later (MoT, 2008, p. 42-45).

In May of 2009, the vehicle scrappage trial for Wellington and Christchurch combined was initiated (MoT, 2009, p. 4). Mechanisms for incentivization were increased during this second trial, with the consumer trading in their vehicle in exchange for not only a public transportation permit, but also for a cash pay-out based on the vehicle they provided for scrap (MoT, 2009, p. 5). Trade-in vehicles were weighed at selected scrap sites, with the scheme then matching the present-day scrap metal worth based on the car's mass and provided this to the participant as payment reward (MoT, 2009, p. 5). Moreover, the scheme included its own competition draw, the prize being a brand-new Toyota Corolla. The option to enter the draw was only available to those who had participated within the trade-in (MoT, 2009, p. 5).

The 2009 vehicle scrappage scheme was intended for the same prospective environmental benefits as the earlier 2007 trial: a decrease in older, less emissions-efficient vehicle ownerships and a consequential increase in the uptake of more sustainable public transportation alternatives (MoT, 2009, p. 4). Even with the multiplied causes for incentivization, or scrap value payment and competition entering in addition to the original exchange for a public transportation pass (MoT, 2009, p. 5), the programme only received a slight increase in participation numbers as a result, with 349 cars being scrapped (MoT, 2009, p. 3). Cars included in this trial showed an average lifespan of 20 years, and an end-of-life odometer reading of 214,500km (MoT, 2009, p. 3).

Doubling the trade-in offer, or measures for motivated participation, meant that governmental spendings also increased (MoT, 2009, p. 38). After the three weeks of trial time (MoT, 2009, p. 3), it was determined that the cost was not worth the participation rates these schemes were receiving, no matter the level of incentivization offered (MoT, 2009, p. 39), with the closing of the Wellington and Christchurch trial concluding the discussion and experimental implementation of car retirement programmes in New Zealand for the next 13 years.

Parliament dialogue surrounding the 'Clean Car Programme', referring to all vehicle type transitions policy for emissions reduction as a collective movement (MoT, 2025), entered the proposed 'Clean Car Upgrade scrappage scheme', also known as the 'Cash for Clunkers' programme (New Zealand Parliament, 2022). Being the first attempt at reintroducing vehicle retirement policy in New Zealand since the trials of 2007 and 2009, the 2022-2024 Hansard House report for the 22nd – 24th of November 2022 states that the scheme was allocated a spending allowance of \$569 million towards the project and, assuming the expected level participation was to be reached, would contribute to emissions reduction by decreasing approximately 4,500 t of CO₂-eq through the removal and disposal of inefficient ICE vehicles (New Zealand Parliament, 2022). Nonetheless, the following Hansard House report on the 4th of April 2023 recorded members contesting the impact of this scheme, considering the overall cost required of its implementation and unguaranteed success (New Zealand Parliament, 2023). As a consequence, it was decided that other methods of emissions reduction within the 'Clean Car Programme' were more appropriate and should be focused instead, and the proposed 'Cash for Clunkers' was revoked entirely (New Zealand Parliament, 2023).

2.2.1.2 Clean Car Discount

In 2021, the Clear Car Discount was enacted to act as a form of financial incentivization targeted at motivating EV uptake to make the purchase of such a vehicle not only more appealing, but also more feasible to New Zealand drivers (MoT, 2025). Compared to early vehicular emissions reduction programmes, such as the scrappage trials detailed above, the Clean Car Discount experienced a more prolonged presence within the realm of New Zealand vehicular policy, with the subsidy active from July 2021 to December 2023 (MoT, 2025). With EVs deemed as the ideal vehicle type for emissions reduction, hence their targeted incentivization, consumers received a payment, determined based on the particular vehicle model's emissions contributions score from factory, towards the EV's purchase (MoT, 2025). Consumers purchasing a brand new EV model were granted a higher rebate quantity towards the purchase of their vehicle as a result of the increased prospective benefits it would have upon emissions reduction (MoT, 2025). The procurement of a second-hand EV, hybrid or low emission vehicle meant that consumers also received financial assistance towards the purchase of the vehicle, however of a lesser amount due to not having quite as much of an expected impact upon emissions reduction targets through privately owned vehicle operation (MoT, 2025). Consequently, the purchase of an ICE or higher emissions vehicle were liable for high cost fees (MoT, 2025).

The Clean Car Discount proved to be the most successful vehicular emissions reduction programme to date with a grand total of 192,082 rebates accepted and paid to the consumer towards the purchase of their new EV or low emission vehicle (NZTA, 2024, p. 4). Even so, the Clean Car Discount came to an end in December of 2023, according to Waka Kotahi The New Zealand Transport Agency,

due to apprehensions surrounding the feasibility of such substantial payments to an increasing number of consumers for an extended period of time (MoT, 2023, p. 1). Whilst the goal for accelerated EV uptake was achieved (NZTA, 2024, p. 3-5), concern surrounding the ongoing cost these rebate payouts would have upon government spending was raised and eventually became one of the lead decisions to disestablish the rebate (MoT, 2023, p. 11). The subsidy was also revoked based on the perception that EVs were becoming more common and therefore more affordable, and that the discount was soon become simply a non-vital added gesture, rather than an incentivization (MoT, 2023, p. 2). However, even after the abolition of the Clean Car Discount, disagreements surrounding the inequity of this scheme were raised, with many arguing that the rebate provided essential financial assistance needed to purchase an EV, or something which provided an avenue to participate in the movement towards net zero emissions, which would otherwise have been a struggle, or even not feasible, for many consumers (MoT, 2023, p. 2).

2.2.1.3 RUC exemptions

An earlier policy from 2009 included the exemption of road user charges (RUC) for light EVs (NZTA, 2025a). Unlike the Clean Car Discount, this policy, whilst enacted during the same time period, was present until its repeal in the recent year of 2024, with light EVs becoming liable for RUC from April 1st 2024 (NZTA, 2025a). The exemption of RUC for EVs was also intended as an incentivization for the uptake of EVs, serving as an additional motivator alongside the Clean Car Discount (NZTA, 2025a). Although repealed, the exemption of road user charges was not disestablished entirely. Now, only larger-sized EVs, or EVs weighing over 3.5 tonnes, are excluded from RUC (NZTA, 2025b), meaning that light, privately-owned passenger EVs that were once incentivized by the government now come with the same obligations or fees as that of the ICE counterparts they were once incentivized against (NZTA, 2025b).

2.2.1.4 Emissions standards

Finally, the most recent policy, being the updated Land Transport (Clean Vehicle Standard) Regulations of 2022, revolves around the mechanism of fining importers and/or owners of imported vehicles that show a high emissions contribution figure (MoT, 2022, p. 1-3). For instance, ICE vehicles imported into the New Zealand incur additional importation fees based when entering the country if the car emits above a certain emissions level, but comparatively allow the importer to gain credits if the car emits below this threshold (MoT, 2022, p. 2). The purpose of this legislation is to disincentivize the importation of high emissions vehicles into New Zealand as much as possible through the addition of high-priced penalty charges as a way of motivating importers more towards the procurement of lower emissions vehicles seen as beneficial for emissions reduction targets (MoT, 2022, p. 1). Section 167C of the Land Transport Act 1998 reflects these regulations as more than an available scheme or programme, such as the previously discussed strategies for vehicular emissions

reduction, but rather as an official piece of legislation and policy to be enforced and followed accordingly (MoT, 2022, p. 2).

As detailed above, with frequent changes in government due to the electoral system where nationwide elections take place every three years (DPMC, 2023), policy, planning, programmes, and strategy schemes for vehicular emissions reduction in New Zealand has rarely experienced a consistent agenda or any lengthy policy capable of surviving the frequency of changing parliamentary term periods. The election of a differing coalition every three years brings different perspectives, priorities, and understandings to the political scene of vehicle-based emissions reduction, meaning no clear direction or mechanism for achieving this aim has remained fixed or without disestablishment. As a result, the need for such consistency stands as a clear objective for this research.

Nevertheless, a degree of influence in the New Zealand vehicular space has been observed due to these policies, which are vital to the understanding of the status quo, and how the results of this research can assist the existing policy landscape to achieve better private vehicle emissions reduction for New Zealand.

2.2.2 International

In contrast to the New Zealand vehicular policy context, international examples tend to show more long-standing approaches, and therefore display different emissions reduction results when compared to that of the New Zealand context. Many countries across the globe, namely including China, London, Germany, and Italy, have implemented policies aimed at encouraging the uptake of specific vehicle types deemed most effective for emissions reduction, with the following examples illustrating these through specific case study examples.

2.2.2.1 Norway

Norway stands as the first country in which EV sales exceeded that of ICEs (Ritchie, 2024). Electric vehicles make up over 90% of the new vehicles sales in Norway (Ritchie, 2024), making the country a world-leader in sustainable private transportation uptake. Such success can be contributed to its various EV policies, including a tax system that penalises higher emissions vehicles with higher tax obligations and lower emissions vehicles with lower tax obligations, as well as planning-based incentivization, with fast-charging stations being publically accessible along commonly travelled, long-distance routes (Norsk elbilforening, 2025). The number of fast-charging stations matches, and

further incentivizes, that of the EV growth within Norway, with a minimum of 9,000 cars using these fast-charging stations at any given time (Norsk elbilforening, 2025).

2.2.2.2 Asia - China

Recent literature captures that China has experienced a higher quantity of EV sales in comparison to ICEs (Pei, 2025). This is due to increasingly present and highly motivational incentivization programmes targeted at the average driver or vehicle consumer in order to increase this vehicle type uptake for nationwide emissions reduction progression (Pei, 2025). For example, in 2022, new car registrations in China consisted of a 60% to 40% split where electric vehicles make up 60% of total new vehicle sales (Khaleel et al., 2024, p. 5). Explanations behind this include active financial policies produced by the Chinese Government. These policies, which are still utilized and are consistently progressing even today, including namely car scrappage schemes which provide subsidy on newly purchased EVs when customers traded-in their ICE (Pei, 2025). In 2025, the maximum rebate available to Chinese vehicle consumers and drivers towards the purchase of an EV sits at ¥15,000 (Pei, 2025), or approximately \$37,000 NZD. In addition, ICEs eligible for scrappage can be as young as those manufactured within 2018 (Pei, 2025). This means that ICE vehicles that are only 7 years old are considered inefficient for emissions reduction targets in comparison to their EV counterparts, as opposed to the average age of scrapped vehicles involved in the 2007 and 2009 New Zealand car scrappages trials being 19-20 years old (MoT, 2009, p. 3). Intensive subsidies with clear direction as to the desired vehicle type and willingness to achieve these goals is what makes vehicular policy and planning in China successful.

2.2.2.3 United Kingdom - London

A publication by Jayakumar et al (2017) specifically describes case study examples found internationally and explicitly recommends them to the New Zealand context, encouraging follow-by-example action. In particular, the 2013 'ultra-low emissions zone' in London was mentioned, where a delegated area of the city was only occupied or travelled through via low-emissions transportation modes, including EVs (Jayakumar et al., 2017, p. 263). This research points to the multiple benefits generated by a zone such as the ability for this type of policy to not only initiate a decrease in atmospheric pollution but also a generate a concentrated increase in the usage of low-emissions modes of transport within this geographical area (Jayakumar et al., 2017, p. 263). This is achieved by the way in which a low emissions zone incentivizes the use of and opting for public transit options, as well as walking or cycling, by citizens located within the specified area, or for those who need to travel to such areas (Jayakumar et al., 2017, p. 263).

2.2.2.4 The EU – Germany and Italy

Similar to China, and early New Zealand vehicular policy trials, Europe is well-renowned for its widespread utilization of car retirement schemes. Countries of Germany and Italy serve as prime examples of this approach to private vehicle emissions reduction, with both case studies showing positive levels of participation, desired EV uptake, and overall resulting success (Svoboda et al., 2023, p. 8). Current literature shows that, within 2009, Germany, under 'trade-for-EV' schemes, offered a fixed downpayment subsidy budget of 2,500 EUR, or \$5,100 NZD, for each ICE exchanged to be scrapped, to be put towards a new EV with higher emissions standards (Svoboda et al., 2023, p. 22). Not only was this the case, but ICEs younger than one year were accepted for scrap trade-in (Svoboda et al., 2023, p. 22), showing an commitment to optimal emissions reduction through light passenger vehicle ownership.

Italy also had success implementing similar programs from 1997 up until the year of 2009 (Svoboda et al., 2023, p. 23-24), each in the effort of replacing high emission vehicles with more emissions-friendly alternatives for the overall aim of national and global emissions reduction (Svoboda et al., 2023, p. 23). In 1997, the payout for scrapped trade-in vehicles was 800 EUR, or approximately \$1,600 NZD, in addition to a two-year long exemption from paying RUC (Svoboda et al., 2023, p. 23). Moreover, if the subsidy was to be used to purchase a newer, emissions-friendly ICE vehicle, a further 1,500 EUR (\$3000 NZD) was added to the participant, or a further reward of 2,000 EUR (\$4,100 NZD) if the new vehicle was to be an EV (Svoboda et al., 2023, p. 23). After the following year of 2008, where Italy saw it's scrappage scheme payout rate amended to 700 EUR (\$1,400 NZD), with a shorter RUC exemption period of one year (Svoboda et al., 2023, p. 24), the 2009 programme included no RUC exemption, but increased the subsidy reward to 1,500 EUR (\$3000 NZD). It was clear through the continuation of vehicle retirement programmes throughout these years that European countries found positive levels of success in the utilization of such policies, investing millions into trialling different rebate conditions across various countries in reverence to the strive for emissions reduction through private, light passenger vehicles (Svoboda et al., 2023, p. 2-3).

2.3 Summary

In summary, the above sections provided foundational information crucial to the remainder of this research. LCA, defined as "an analytical tool for the systematic and quantitative evaluation of the environmental impacts of a product or service system through all stages of its life" (LCANA, 2019), is applicable to this research by serving as a base tool for calculative analysis specific of lifecycle total and phase emissions quantities specific to New Zealand data, in addition to the providing context to upcoming literature review surrounding vehicle type studies of a similar nature.

As for the policy background, New Zealand reflects a nonlinear timeline of unsteady mechanisms for incentivizing desired, emissions-friendly vehicle types, portraying a policy landscape that is in dire need of consistent, long-standing agenda in order to achieve substantial results. Key examples including the revoked Clean Car Discount and multiple, short-lived vehicles scrappage schemes portray this indefinitely. Whilst a degree of success was achieved through these strategies, the absence of a clear direction and unsteady policy lifespan means that the emissions reduction results of such initiatives cannot be harnessed to the full and therefore require reconfigured planning and policy-based adjustments recommended based on the findings of this research.

International case studies to be noted include car scrappage schemes in China, Italy, and Germany, where sizeable subsidies were offered to consumers in order to motivate them to trade-in their ICEV for a low-emissions EV model, and proved to be greatly successful as shown by scrapped car numbers and a drastic rise in EV sales. This serves as a real-world example of fruitful vehicle type policy and planning to assist that of New Zealand. However, none of these case studies, domestically and internationally, considered the characteristics of the EVs being incentivized, such as the size of the vehicle or even the expected driving distance it is intended for in utilization, both of which represent values that are intrinsic to the LCA score of the vehicle. This points to a gap within the current vehicle policy trajectory worldwide, further presenting another reason for this research investigation.

Chapter 3

Literature Review

3.0 Introduction

The following literature review provides a summary of pre-existing studies surrounding vehicle type LCA. Literature, namely academic journal articles, showing LCA studies of a similar nature to this research surrounding vehicle type LCA are summarized and analysed in terms of the methods they used, what was successful, what was less successful, and the overall findings in terms of vehicle type emissions reduction results. The literature review begins with a general-scale analysis, detailing papers with a core focus on emissions-based lifecycle impact of ICEs versus EVs. The remainder of this chapter, however, assumes a more prescribed approach, delving into LCAs showing discussion surrounding more specialized themes of driver behaviour, such as driving distance and vehicle lifespans, and the role of EV batteries and their replacement upon LCA. Finally, providing direct comparison to the methods and findings of this dissertation, vehicle type LCA studies undertaken within the New Zealand context are explored, allowing for later analysis pertaining to the similarities and differences of this research to that of existing kindred studies within the same geographical and policy conditions.

3.0.1 Lifecycle impact assessment and greenhouse gas emissions

Vehicle type LCA from a greenhouse gas emissions perspective is the most common form of research seen within pre-existing literature. With greenhouse gas emissions contributions being the core focus of vehicle type and ownership policy, studies reflecting this are seen far and wide within the literature.

‘Comparative environmental life cycle assessment of conventional and electric vehicles’ - Hawkins et al. (2013):

The ‘Comparative environmental life cycle assessment of conventional and electric vehicles’ study takes on a scope that is fully focused upon purely on the greenhouse gas emissions of different vehicles (Hawkins et al., 2013, p. 53). Different vehicle types involved in the study included both ICEs and EVs, with each life cycle phase of each being assessed in terms of its impacts and then compiled together to create the total LCA of these vehicles (Hawkins et al., 2013, p. 54-56). The research was conducted in a way which created data catalogues for each vehicle type and used this standardized data, in methodology based on ISO 14041/ISO 14044 regulations, to calculate the life cycle impacts each per vehicle kilometre for in-depth analysis (Hawkins et al., 2013, p. 53-56).

The study, being a highly cited piece of literature within the realm of vehicle type LCA, produced key findings concluding that EVs were the most emissions-efficient vehicle type option, due to their net zero operations-based emissions contributions, yet do carry large manufacturing-based emissions, which therefore need to be compensated for by being driving proportionately in order to override this payback point (Hawkins et al., 2013, p. 58-59). Due to this, even though the study determines EVs as the best vehicle type option for private passenger vehicle emissions reduction, based on its ability to supersede this payback point (Hawkins et al., 2013, p. 60-61), the researchers also highlight the potential for EV to be the worse alternative in other environmental areas, such as landscape pollution and toxicity to humans, based on this extensive manufacturing cost (Hawkins, 2013, p. 60-61).

This is where potential limitations for this research arise. With the study now reaching an age of 12 years, data used for this study will be highly different to what is known about the impacts of EVs, both emissions-based and further, and so therefore might not be entirely applicable to the vehicle type LCA landscape of today without some degree of refinement or revision. In addition, all operations-based emissions contributions data pertaining to ICEs used within the study is based on statistical modelling (Hawkins et al., 2013, p. 54), not real-world data. This opens the opportunity for further concern surrounding the study's accuracy, especially when considering the origin areas of the data being limited to the EU (Hawkins et al., p. 53), and therefore not entirely representative of the energy mixes of the rest of the world (Hawkins et al., 2013, p. 60).

'Cleaner cars from cradle to grave' - Nealer et al. (2015):

'Cleaner cars from cradle to grave' details another early LCA comparing both EVs and ICEs, this time within the geographical context of the USA (Nealer et al., 2015, p. 2). As seen within the title, the study takes on a "cradle-to-grave" approach, meaning it assesses the basic lifetime phases of production, well-to-tank, tank-to-wheel, and disposal, in order to determine the emissions impacts associated with each (Nealer et al., 2015, p. 1-2). Typical early EV models of the time, including the Tesla S and the Nissan Leaf were used as standards for the EV-relevant data used, with ICEs counterparts, based on fuel efficiency equivalents, were represented in profiles of vehicle size determined by the study as a form of equal comparison (Nealer et al., p. 17-18).

Findings concluded, once again, that EVs are the best for emissions reduction causes due to their lower total life cycle emissions numbers, producing approximately half the life cycle emissions of their equivalent ICE counterparts (Nealer et al., 2015, p. 1-2). Also in repetition of other LCA work, results pointed towards higher manufacturing emissions corresponding to EVs (Nealer et al., 2015, p. 21-22), but states that the net zero emissions contributions within the operations phase compensate for this due to the large distances travelled by American drivers (Nealer et al., 2015, p. 12). The study

recognizes its own limitations by recognizing the nascent nature of EVs at the time of investigation, and that this means the data and results from this study is inevitably up for change considering EV growth and evolution within the coming years since this study (Nealer et al., 2015, p. 6-7).

'A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars' - Bieker (2021):

A more recent vehicle type LCA is the 'A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars'. Like to two earlier case studies detailed above, this research also solely focuses on the emissions associated with each vehicle type, these being EV and ICE, but extends to a larger, more diverse and representative geographical context of America, China, India, and Europe, rather than a single country of focus (Bieker, 2021, p. i). Data for this LCA concerning these vehicles was obtained by using the vehicle registration analytics from the year of study, this being 2021, and the projected vehicle registrations for the upcoming year of 2030 (Bieker 2021, p. 8). This makes this study increasingly reliable to the current time period of this dissertation research, and a good literature piece to review as a result.

Key findings involved the determination of EVs having the lowest LCA score, however this time by much a further margin than that of previous studies, with the paper stating that EVs "offer the lowest life-cycle emissions compared to the currently dominant gasoline vehicles" (Bieker, 2021, p. 41). Due to different emissions factors and regional energy make-ups, EVs within Europe tend to show the most positive emissions reduction results, producing 66-69% less emissions than ICEs within the same area, whereas those within India only emit 19-34% less GHG emissions compared to their ICE counterparts (Bieker, 2021, p. i). The paper also argues that these gaps are only expected to progress positively in favour of EV superiority due to expected renewable energy developments between the time of study and the year 2030 (Bieker, 2021, p. ii), but the progression of ICEs in terms of emissions reduction does not show any promise of improvement, therefore making these vehicles the less preferred option, and possibly one that will see a decrease in uptake numbers as a result (Bieker, 2021, p. ii). Whilst various countries were considered, there was no consideration for fluctuating driver distances or vehicle lifespans, leading to some discrepancies between the trends of real-world driving and vehicle ownership LCA, despite the recent nature of this research.

3.0.2 Lifecycle impact assessment and driving behaviours

Within this dissertation, driver behaviours refer to the specifics surrounding the utilization of a vehicle by its operator or owner. Driver behaviours therefore involve variables such as the lifespan of the vehicle, or, in other words, how long the vehicle is kept on the road by its owner(s), and the daily distance undertaken by the driver and vehicle, measured in km/day, or the total lifetime distance

travelled by the vehicle, also known as the end-of-life odometer reading recorded at the time of disposal. Each of these driving behaviours lead to different vehicle characteristics that influence the LCA results generated, hence the inclusion of this discussion with pre-existing studies and this literature review.

'Sensitivity analysis in the life-cycle assessment of electric vs. Combustion engine cars under approximate real-world conditions' - Helmers et al. (2020):

Helmers et al. (2020) performs a LCA of both EVs and ICEs within the scope of Germany (Helmers et al., 2020, p. 1-3). A multitude of life cycle impacts are assessed, including environmental, or greenhouse gas emissions, but also social effects, such as human health impacts from resulting air pollution (Helmers et al., 2020, p. 1-3). In order to provide a full recognition for and representation of the different vehicle characteristics and driver behaviours involved, a range of vehicle lifespans, electricity consumption rates of the vehicles, battery replacement options, vehicle size, and distance travelled where all included within the variables used, allowing for that "real-world", representative analysis (Helmers et al., 2020, p. 1). Instead of relying solely upon external resources for these LCA input values, the team of researchers actually conducted an experiment using a modified electric vehicle of their own, running tests upon this test subject to generate and collect data figures based on multiple possible combinations of driver behaviours and vehicle characteristics, which they could then use within their LCA (Helmers et al., 2020, p. 4-8). It was believed that this, too, would add to the accuracy, representation of, and applicability to that of real-life vehicles (Helmers et al., 2020, p. 1).

Key findings demonstrated a clear superiority of the test subject EV, namely due to its lesser contribution of greenhouse gas emissions into the atmosphere (Helmers et al., 2020, p. 12), despite ICE vehicles, which were calculated using existing data sources, showing more positive results in aspects as such less landscape pollution or less toxicity of materials to humans (Helmers et al., 2020, p. 13-15). A more interesting find of the study, however, demonstrated that EVs were only significantly better for emissions reduction than ICEs when the driver behaviours exhibited were proportionate to that of the vehicle's characteristics (Helmers et al., 2020, p. 12). For instance, an EV that is driven lots will produce positive emissions reduction benefits due to overriding its initial manufacturing emissions and therefore harnessing the net zero emissions appeal of EVs during its operation (Helmers et al., 2020, p. 12). This means that its "break-even point", or the point where the life cycle emissions, or impacts, of an EV becomes lesser than its ICE counterpart, is reached faster when it is driven more and through the extension of its lifespan, which in return increases the total lifetime distance (Helmers et al., 2020, p. 12-15). This not only proved the role of different

driver behaviours upon the lifecycle efficiency of a vehicle, but it also demonstrated this through using different variables to test the extend of this theory (Helmets et al., 2020, p. 12).

Limitations to the study can be found within the generalization of the data and test subject conditions used. Whilst changing variables such different distances, lifespans, and options for or without battery replacement as utilized to represent various driver behaviours and this impact upon vehicle type LCA, there was only one test subject vehicle tasked with generating the other experiment-based data figures, this being a Volkswagen Caddy (Helmets et al., 2020, p. 1). By only testing these profile scenarios on this one vehicle model, it is difficult to imagine that aspects such as electricity consumption and vehicle mass weight were able to be adjusted to represent multiple different vehicles that are not of a similar manufacturing style. This means that the results are limited to certain vehicle types and may therefore not apply to vehicle types not modelled, potentially render this experimental side of the study not as entirely universally applicable as the researchers has hoped.

‘Automotive electrification challenges shown by real-world driving data and lifecycle assessment’ (2022) and ‘Electric vehicle uptake: Understanding the print media’s role in changing attitudes and perceptions’ (2021):

Neidhardt et al (2022) uses real-world data recording the driving behaviors (e.g. distance, stops, attitude of drivers) in a New Zealand context, and thereby predicts the type of driver likely to purchase an EV, and what vehicle types would have the least impact based upon their existing driving habits and transportation requirements. By using this real-life data taken from real citizens who own and operate vehicles on a regular basis, the article determines an “optimal drive train mix” and found that EVs would have the least impact on the environment whilst catering to the current needs of the consumer without having to change their behaviors (Neidhardt et al., 2022, p. 1).

Broadbent et al (2021) also did a similar study in the New Zealand context where driving behaviors were assessed in order to predict the likelihood of a NZ citizen purchasing an EV. Based on the findings of this study, where only a certain type of New Zealander might be interested in purchasing an EV due to the needs of their driving behaviors, researchers were able to understand the challenge of encouraging or implementing change in individual driver behaviors and rather assess the kind of EV different consumers would be looking for dependent on their current driving needs and desires (Broadbent et al., 2021, p. 174). These sources raise an important hypothesis where, if EVs do indeed have a lower emissions impact, then, based on different types of vehicles and driving behaviors, EV

incentives have the potential to be more successful when targeted at certain groups in relation to these specific vehicles and driver types.

3.0.3 Lifecycle impact assessment, EV batteries, and battery replacement

EV batteries have an impact on the vehicle's LCA result due to emissions contributions associated with each process involved. This namely includes, but is not limited to, emissions impacts associated with battery production, size, range capacity, and replacement. Being processes that are only relevant to EVs and not ICEs, each aspect of the EV battery, from production to replacement, highlights extra considerations for vehicle type LCA, and influences the LCA score of EVs as a result.

'The size and range effect: Lifecycle greenhouse gas emissions of electric vehicles' - Ellingsen et al. (2016):

Unlike the literature discussed in the sections above, this study limits discussion comparing EVs with ICEs, but rather focuses solely on the LCA results of EVs, comparing EVs with other EVs of different sizes and battery range capacities instead (Ellingsen et al., 2016, p. 1). As a result, the cradle-to-grave perspective consists of the production phase, the charging phase, and the end-of-life phase of such batteries (Ellingsen et al., 2016, p. 1). These EVs, or, more precisely, batteries, are compared by the overall GHG emissions they produce (Ellingsen et al., 2016, p. 2-3), which was tested in different electricity mix scenarios, such as gas power, wind power, and coal power energy generations forms, in order to assess the difference in LCA GHG emissions contributions of each (Ellingsen et al., 2016, p. 2-3). A standard of 180,000km lifelong distance was used as a threshold for measurement, representing the average lifelong distance for vehicles within this study (Ellingsen et al., 2016, p. 3).

Core findings included the determination of larger EV batteries as the highest GHG emissions option, these contributing the most GHG emissions no matter the energy source origin (Ellingsen et al., 2016, p. 4-5). When it comes to the 180,00km/vehicle average, the study found that small to medium-sized EV/ EV batteries are the best for emissions reduction as these size, travelling this lifetime distance, emit less GHG emissions across their lifecycle when compared to ICE equivalents as a result of having a smaller battery better suited for emissions reduction (Ellingsen et al., 2016, p. 5-6). EVs of a larger size, however, whilst emitting more GHG emissions than smaller-sized EVs, remain better for emissions reduction than any ICE counterpart by a 20-27% (Ellingsen et al., 2016, p. 4). The carbon-intensity of EVs within their earlier lifecycle phases remains a point of discussion, due to the production of the battery being an additional emissions-contributing processes only relevant to EVs (Ellingsen et al., 2016, p. 4-6). Interestingly, this study provides little discussion or evidence surrounding the impacts of battery replacement upon EV LCA. Instead, authors discuss and calculate the disposal of these batteries, something which appears different from the rest of the literature.

Their investigations found that end-of-life practices for the disposal of an EV battery is 14-23% more harmful for the environment, on an emissions basis, than processes in relation to the disposal of an ICE battery (Ellingsen et al., 2016, p. 5).

'The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries' - Romare & Dahllöf (2017):

This research focuses only within the boundaries of EV battery production LCA (Romare & Dahllöf, 2017, p. 2), providing no discussion or investigation into the other life cycle phases of well-to-tank, operation, of end-of-life/recycling. Instead, the phase of production is dissected into its own life cycle stages of mining, material extraction, manufacturing of parts, and construction (Romare & Dahllöf, 2017, p. 3), all of which are assessed in terms of GHG emissions impacts and collectively determine the overall LCA score for the production phase of each EV battery size (Romare & Dahllöf, 2017, p. 3). Impacts of each battery type are assessed and expressed in kg CO₂-eq/kWh of battery capacity (Romare & Dahllöf, 2017, p. 3), in terms of the GHG emissions contributions throughout the production phase (Romare & Dahllöf, 2017, p. 3). Data to conduct these calculations was gathered from previous studies that include breakdowns surrounding data pertaining to energy consumption, greenhouse gas emissions, and different manufacturing materials (Romare & Dahllöf, 2017, p. 3).

The paper found that li-ion batteries, at the time of this study, are responsible for an estimated 150-200 kg CO₂-eq/kWh of emissions during production (Romare & Dahllöf, 2017, p. 38-39). Energy used for the production of these batteries equates to anywhere between 350-650 MJ per kWh (Romare & Dahllöf, 2017, p. 38-39). Whilst the most emissions contributions within the EV battery production phase correspond to the actual manufacturing of the battery (Romare & Dahllöf, 2017, p. 40-41), less emissions are associated with the mining of raw materials for this production, yet the true concern for the mining stage lies in a more social or ethical paradigm rather than environmental (Romare & Dahllöf, 2017, p. 40-41).

Challenges to the research involve its total neglect of the operations and recycling phases of EV batteries. Whilst it is beneficial to understand the impacts associated particularly within this stage, with EVs proving to hold more emissions within these earlier processes in comparison to ICEs (Romare & Dahllöf, 2017, p. 40-41), a true LCA looks at a product from an all-encompassing, holistic approach (LCANA, 2019). Focuses solely on one area without dedicating any attention to other contributing phases could be seen as inferior LCA practice.

3.0.4 Lifecycle impact assessment of vehicle types in New Zealand

The majority of vehicle type LCA research derives from Europe, the USA, and China. However, there are some studies that pertain to the New Zealand context, using New Zealand-specific data and

making policy recommendations for the nationwide fleet, and are therefore incredibly relevant as literature within the same field of impact as that of this dissertation. These studies are discussed in detail below.

'Life cycle assessment of electric vehicles: The environmental impact of electric vehicles, a New Zealand perspective' - EECA (2015):

Being the first of its kind, the 'Life cycle assessment of electric vehicles', produced by the Energy Efficiency and Conservation Authority (EECA), used a cradle-to-cradle LCA approach to compare EVs the environmental impacts of EVs within New Zealand to that of ICE vehicles (EECA, 2015, p. 5). This cradle-to-cradle approach encompassed all areas of the lifecycle, these being material extraction, production, delivery, tank-to-wheel, and even battery recycling processes (if applicable to the vehicle type) (EECA, 2015, p. 5-7), with the LCA used built upon ISO 14040, or 14044, standards (EECA, 2015, p. 33). Data used to calculate emissions pertaining to these lifecycle phases was collected from current vehicle manufacturing process reports and New Zealand electricity figures of the time (EECA, 2015, p. 33-43). Whilst the scope focused entirely on the New Zealand context, the lifecycle impact analysis went beyond that of greenhouse gas emissions, looking into other environmental impact areas such as energy and resource demand and supply and human health effects as well (EECA, 2015, p. 56-64).

The study found that EVs contribute lower greenhouse gas emissions on a total life cycle basis in comparison to ICES (EECA, 2015, p. 44) and that their resource and energy consumption impacts are therefore of a similar scale, demanding no more resource and electricity than that of an ICE (EECA, 2015, p. 44). Human health impacts, within the study's scope of New Zealand, were found to be impacted more from ICEs due to their tank-to-wheel particulate emissions, in comparison to an EV which gives off net zero emissions when in operation (EECA, 2015, p. 44-56).

Challenges to the EECA 'Life cycle assessment of electric vehicles' study revolved around the use of assumptions or international data for many input values used in the LCA (EECA, 2015, p. 33). This included using the European-based ecoinvent v3.1 Lifecycle Inventory Database to determine the average small vehicle weight and global fuel production data, both of which were kept as standard throughout the study (EECA, 2015, p. 33-40). Not all data was New Zealand-specific, despite the domestic intention of the investigation, and was therefore taken from international or external sources to fill the needed gaps (EECA, 2015, p. 33-34). In addition, with the study being published in 2015, and being the first New Zealand-specific vehicle type LCA of its kind, the researchers were not entirely confident in the processes involved in recycling or disposing of certain vehicle types, mainly EVs, as these models has not been in the fleet long enough to provide experience within these areas

(EECA, 2015, p. 66). International case examples were also relied upon for such calculations and analysis (EECA, 2015, p. 64), once again highlighting similar concerns.

'Costs and emissions: Comparing electric and petrol-powered cars in New Zealand' - Hasan et al. (2021):

Hasan et al. (2021) performs an investigation where LCA is conducted from two different perspectives. These perspectives included the greenhouse gas emissions impacts of each vehicle type as well as the total cost of ownership associated with each vehicle type over its lifetime (Hasan et al., 2021, p. 1-2). Both approaches, however, did include the recognition of the different driver behaviours, for instance how far the car was driven, and made sure to include the role this variable played within LCA results (Hasan et al., 2021, p. 5). Controlled variables included the single context of New Zealand, a set vehicle lifespan of 12 years for all calculations, and a standard of comparison between EVs and ICEs (Hasan et al., 2021, p. 5).

Results found that EVs were the most beneficial vehicle type, on a life cycle basis, from both a greenhouse gas emissions focused as well as a total cost of ownership basis (Hasan et al., 2021, p. 6-9). EVs produced lower emissions contributions than ICEs, and even though the addition of higher manufacturing emissions and potential battery replacement emissions impacted these results (Hasan et al., 2021, p. 6), EVs still remained the more emissions-friendly option in each scenario when compared to ICEs (Hasan et al., 2021, p. 6). From a cost perspective, EVs again remained the most efficient option due to having far less mechanical parts, thereby needing proportionately less maintenance and repairs than that of an ICE (Hasan et al., 2021, p. 7).

Challenges to the research once again included the inevitable susceptibility of the necessary time-allotted data to fluctuate, requiring a continued need for reassessment in order of the results to stay accurate. In addition, a lot of data figures used were also assumed and therefore made into one fixed, static variable. This included maintenance costs, vehicle lifespans, electricity consumption rates, and vehicle purchase prices (Hasan et al., 2021, p. 5). Again, this means that the study is confined to a specific time period and vehicle profile, leaving less opportunity for timeless, applicable policy and planning implications.

'Electrification of New Zealand Transport: Environmental impacts and role of renewable energy' - Reguyal et al. (2023):

Unlike the previous two New Zealand-based studies, the paper 'Electrification of New Zealand Transport: Environmental impacts and role of renewable energy' does not compare EV and ICE LCA, but rather just focuses on investigating and providing information surrounding the impacts of only

EVs instead (Reguyal et al., 2023, p. 1-2). Being the most recent publication, published in 2023, the typical life cycle stages of manufacturing, operation, and end-of-life are the focus (Reguyal et al., 2023, p. 1-2), but with additional impact areas such as battery recycling, replacement, varying battery range capacities, and New Zealand's electricity make-up also now made more possible for accurate investigation due to modern data sources and experiences (Reguyal et al., 2023, p. 2-4). The study uses these variables to assess how different quantities of each contribute to the life cycle impacts of EVs in New Zealand (Reguyal et al., 2023, p. 2-4).

Results found that the reason EVs have higher life cycle impacts within certain phases of their life cycle, or when paired with certain battery replacement and distance capacity variables, is due to the battery itself, due to its high manufacturing and replacement emissions (Reguyal et al., 2023, p. 4-7). Results also concluded that different EV models pertain to a wide spectrum of emissions contributions, with small-sized EVs contributing the lowest emissions possible, and larger-sized EVs contributing far more in comparison (Reguyal et al., 2023, p. 4-7). Batteries with a lower capacity are generally found within smaller-sized EVs, yet the study shows that the smaller the battery, the larger the emissions, due to an increased need for charging infrastructure and quicker need of overall replacement (Reguyal et al., 2023, p. 4-7). Similar to previously discussed studies, the replacement of the EV battery, however, will lead to less emissions impacts than the obtainment of an entirely new EV unit, and is the option that should be chosen by consumers (Reguyal et al., 2023, p. 4-7). Challenges were caused by these variables, with assumptions made based on the distances people drove before deciding to charge their vehicles (Reguyal et al., 2023, p. 2-3), and other assumptions made due to a lack in New Zealand-specific data as a result of New Zealand's younger history with EVs compared to other countries.

3.1 Summary

In conclusion, GHG emissions prove to be the most frequently considered impact in terms of EV and ICE LCA comparisons, with EVs, for the most part, showing evidence of a smaller carbon footprint. However, this depends on the vehicle type, weight, driving behaviours, needs of the operator, and national grid capabilities, with the idea and importance of vehicle payback rate evidence across the board. Battery replacement, or the role of EV batteries in general, to the realm of vehicle type LCA was a reoccurring theme in the existing literature, leading to the collective conclusion that battery production and replacement leads to more lifecycle emission yet is still more emissions-friendly than that of an ICE or the production of an entirely new EV unit as part of recognition of the cradle-to-cradle perspective. As for existing New Zealand vehicle type LCA, it is a positive to see research conducted using New Zealand-specific data and circumstantial consideration within each publication listed, with factors such as vehicle lifespan and lifetime distance utilized.

Gaps highlighted within this literature review involve a lack of utilization of vehicle-type ideals for emission reduction, based on driver behaviour and vehicle lifespan findings within the existing research, for making recommendations and implications to vehicular planning and policy. The literature, paying special attention to those LCA conducted within New Zealand, provides results that are applicable to nationwide movements, but fails to link this to individual driver-scale policy incentivization for real-world uptake. In addition, core New Zealand-based research, such as that of the EECA, whilst providing valuable research, is now 11 years old, and therefore leaves concern for the age of the New Zealand-specific data used at the time, raising the question as to how relevant these findings are now due to changes in energy mixes, electricity generation and distribution, driver behaviours, and EV technologies since this study.

3.2 Assessment of lifecycle impact tools

To answer the first research question, an established LCA tool will be selected and used to evaluate the full range of vehicles under analysis. Whilst many LCA tools exist for various different contexts, this research investigates only car-specific applications. LCA tools involve the online data-input calculators and interactive applications for comparing ICEs and EVs produced by organizations who have conducted similar research. Prominent examples include the International Energy Agency's 'Lifecycle Impact Assessment Calculator' which provides both cumulative and lifecycle stage-relevant data based on selected input options (IEA, 2024), the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, with its outputs providing intricate emissions-based and economical information based on their vehicle type and usage data input (Argonne National Laboratory, n.d.), as well as the consumer-friendly Electric Vehicle Council's Lifecycle Emissions Calculator that is easy to access and provides basic information to the user (Electric Vehicle Council, 2023).

The following assessment undertakes a critical analysis and evaluation of these three established tools for lifecycle impact analysis to determine which application is most appropriate and most relevant to the objectives of this research investigation. Factors such as the institutions, inputs required, outputs given, and uses of the generated findings of each tool are identified and reviewed as part of the assessment and selection process.

Table 1 - Assessment of LCA tools characteristics

Tool/Application	Institution	Inputs required	Outputs given	Analysis – What it provides	Where – Usages in literature review	Link for usage
EV Life Cycle Assessment Calculator	International Energy Association	Vehicle type, vehicle size, driving profile, average milage travelled, vehicle lifetime, fuel type, average fuel consumption, EV battery range, average power consumption, if EV battery has been replaced	Cumulative emissions (in comparison to other powertrain/vehicle types over coming years), breakdown of emissions (per specific vehicle, over lifetime or per vehicle km, production and combustion stages), break-even point between vehicle types	Provides comparison data concerning emissions production of all vehicle types, (including ICE, PHEV, and EV) in both a cumulative and breakdown format. The cumulative data shows the total emissions produced by each vehicle type every year going forward, with a cross-over in the data indicating a break-even point between two vehicle types. The breakdown format shows the quantities of emissions separated into the corresponding stages of the lifecycle, including production and/or combustion stages, per a choice of either kilometres travelled or years of vehicle lifespan/ownership length.	Elementale Enterprises Inc. (2024). <i>New IEA online tool compares lifecycle emissions from traditional and electric cars.</i> https://www.elementale-ent.com/new-iea-online-tool-compares-lifecycle-emissions-from-traditional-and-electric-cars#:~:text=The%20online%20calculator%20allows%20users,mix%20used%20to%20power%20them	https://www.iea.org/data-and-statistics/data-tools/ev-life-cycle-assessment-calculator
Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool	Argonne National Laboratory	Vehicle type, powertrain type, vehicle quantity, milage travelled by vehicle per annum, fuel economy, vehicle price, maintenance price, location	Simple payback rate, annual GHG emissions, annual petrol use, annual air pollutants (CO, NOx, PM10, PM2.5, VOC, SOx), lifetime GHG emissions, petroleum use, lifetime air pollutants, total cost of ownership	Different calculators including on-road payback, total cost of ownership data generators. Payback On-Road Calculator: Provides comparison data for entered vehicle types (including ICE, PHEV, and EV) in terms of its simple payback rate (i.e. return of investment expectation), annual petroleum use of the vehicle measured in barrels, annual greenhouse gas emissions measured in short tons, and annual pounds of air pollutants generated, including CO, NOx, PM10, PM2.5, VOC, and SOx. TCO Calculator: Provides comparison data for entered vehicle types (including ICE, PHEV, and EV) concerning GHG emissions, petroleum use, and air pollutants over the course of the vehicle's lifetime, set at 15 years, and therefore the total cost of ownership measured in tens of thousands of USD.	Fuels Institute. (2022). <i>Life cycle analysis comparison: Electric and internal combustion engine vehicles.</i> Ricardo Inc. https://www.transportationenergy.org/research/reports/life-cycle-analysis-comparison-electric-and-internal-life-cycle-analysis-comparison-electric-and-internal	https://afleet.eia.anl.gov/home/#:~:text=Argonne%20developed%20the%20Alternative%20Fuel,%2C%20and%20off%20road%20vehicles.
Lifecycle Emissions Calculator	Electric Vehicle Council of Australia	Location, powertrain/vehicle type, vehicle size, access to 100% green energy option	CO2 emissions per km, lifetime emissions using NEM electricity, tonnes of emissions per distance, tonnes of emissions produced within lifecycle stages of vehicle production, battery production, fuel cycle, and recycling	Provides comparison data of different vehicle types (including ICE, PHEV, and EV) in terms of the carbon emissions produced per kilometre travelled, as well as the emissions generated by each over the course of the vehicle's lifespan, which is measured in tonnes of CO2 per 50,000-kilometre distances travelled. Additionally, this includes a breakdown format displaying the emissions corresponding to different stages of the lifecycle, including production (of both vehicle and/or battery), fuel cycle, and recycling.	Sanchez, J. (2023, November 30). <i>New online tool allows anyone to compare EV vs ICE vehicle emissions.</i> Driven Car Guide. https://www.drivencarguide.co.nz/news/new-online-tool-allows-anyone-to-compare-ev-vs-ice-vehicle-emissions/#:~:text=The%20Australia%2Dbased%20Electric%20Vehicle,states%20and%20territories%E2%80%8B%E2%80%8B	https://electricvehiclecouncil.com.au/lifecycle-emissions-calculator/

Note: Summary table of each LCA tool involved in this assessment, detailing each's institutional source, inputs required, outputs given, analysis provisions, citations in other literature, and links to online applications.

3.2.1 Evaluation

3.2.1.1 IEA EV Lifecycle Assessment Calculator

The EV Life Cycle Assessment Calculator was produced by the International Energy Association in 2024. As a web-based tool, users are required to input necessary vehicle characteristics, including powertrain type, size, fuel type, average fuel consumption, or, in contrast, EV battery range and average power consumption (IEA, 2024). Whilst the average fuel and power consumption figures are calculated by the tool itself given local data relevant to the user's selected location, other more specific details, such as the vehicle lifespan, or length of ownership, and average daily mileage travelled are user defined inputs. (IEA, 2024). Outputs include both cumulative and breakdown emissions graphs. Cumulative emissions data displays the total emissions produced by each the vehicle type every year going forward, with a cross-over in the data indicating a break-even point between two vehicle types (IEA, 2024). The breakdown format shows the quantities of emissions separated into the corresponding stages of the lifecycle, including production and/or combustion stages, per a choice of either kilometres travelled or years of vehicle lifespan/ownership length (IEA, 2024).

Advantages of the IEA EV Life Cycle Assessment Calculator involve the ability given to the user to view the emissions data from both a lifetime perspective and from a per kilometre basis. With the research questions for this investigation seeking to understand both vehicle type sustainability and also how driving behaviours relate to this, having the option to view the generated results from both scales would prove to be highly useful. Secondly, this web-based tool further serves its user by automatically providing vehicle-specific information that may not be so well-known to the average consumer by utilizing pre-existing figures corresponding to the basic inputs which the user can be expected to give, such as vehicle type and size. These additional, more intricate input values provided by the application itself include the average fuel consumption, power consumption, and utility ratings relevant to certain powertrains (IEA, 2024) and are approximate, or recommended rather than set, allowing the user the ability to change them should they know the exact figures relevant to their vehicle's make and model for increased accuracy. The fact that this tool is built upon credible background data surrounding these areas and is able to evidence this in their provided methodology statement (IEA, 2024, p. 1), means that not only can users rely on the tool's provision of such specific knowledge, but they can also trust the reliability of these built-in assumptions through the fully transparent and easily accessible evidential workings provided.

On the other hand, disadvantages such as the limited country selection options have the potential to be hurdles for this location-based analysis. The EV Lifecycle Calculator, whilst providing the choice of many region or country input options, or even a “world”/global viewpoint (IEA, 2024), New Zealand, or any other Oceania nations for that matter, is missing from the list. This leads to the concern for decreased accuracy in the output data results as the selection of country or region provides the tool with the background information concerning localized petrol and electricity provisions or prices, rather than “world” average figures, and therefore cannot provide the New Zealand-specific data that this research requires. In addition, not only does the tool stop at the operation, or combustion, stage of the life cycle, it also is limited to being entirely emissions focused, thereby outputting no information beyond these and lacking the ability to extend this analysis to impacts wider environmental impacts such as air pollution .

3.2.1.2 Alternative Life-Cycle Environmental and Economic Transportation (AFLEET) Tool

The Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool is an online application that contains five separate calculator tools for generating data surrounding the pay-back, for both on and off-road automobiles, total cost of ownership, not only for vehicles but also EV charging stations, and EV rates for fleet-scale operations (Argonne National Laboratory, n.d.). The payback on-road calculator and the total cost of ownership calculator hold the most relevant to the scope of this study. These two calculators require relatively general input values such as location, vehicle type, powertrain type, vehicle quantity, mileage travelled by vehicle per annum, and fuel economy rate. Additionally, more intricate entries, being the initial cost of the vehicle, in US dollars, and regular maintenance costs, in dollars per mile, are able to be input to increase the accuracy of the result generated, especially when considering the desired payback rate and total cost of ownership outputs provided (Argonne National Laboratory, n.d.). Other outputs beyond the monetary scope include both annual and lifetime production of GHG emissions, annual air pollutants, covering elements of carbon monoxide, nitrogen oxides, PM10, PM2.5, volatile organic compounds, and sulfuric oxides, and, finally, annual petroleum usage figures (Argonne National Laboratory, n.d.).

Similar to the above IEA EV Lifecycle Assessment Calculator, the AFLEET tool is limited in terms of the available geographic options. AFLEET, due to its origins, only allows the user to select which state the vehicle is used in, meaning the outputs provided derive from background information that is specific to the United States of America (Argonne National Laboratory, n.d.). Again, there is no New Zealand input option. What’s more is that the application displays input requirements for various technical features and figures relevant to the vehicle being assessed, including the initial cost of the vehicle paid (\$ USD amount) and the cost of maintaining the vehicle (\$/mi) (Argonne National Laboratory, n.d.). Although, it could also make generating data for a more generalized vehicle type research

investigation, such as this one, slightly more complicated. Therefore, averaged values surrounding these more technical inputs would need to be decided upon and used for generated more widespread results whilst still balancing the need for accuracy.

From an advantage point of view, the AFLEET tool outputs not only emissions-based data, but also monetary-focused impacts throughout the lifecycle stages. Payback rates and total cost of ownership (TCO) (Argonne National Laboratory, n.d.) can be generated through this same recipe of inputs, including the few additional, more technical requirements, allowing a more holistic view of the vehicle's impacts. For all impacts accounted for, both lifetime and annual figures can be shown. What's more, AFLEET delivers data on the effects at all basic stages of the lifecycle, including vehicle and battery productions, fuel cycle operation, and recycling (Argonne National Laboratory, n.d.), something which this research investigation also seeks to provide, making this tool very useful in this manner alone.

3.2.1.3 Electric Vehicle Council Lifecycle Emissions Calculator

In 2023, the Electric Vehicle Council of Australia published an interactive tool targeted at local drivers in order to provide them with approximate figures surrounding the emissions generated by different vehicle types and throughout the chronological stages of its lifecycle (Electric Energy Council, 2023b, p. 3). Consumers merely need to input basic information about their chosen vehicle, with the application only requiring the user's region of residence, powertrain type, and vehicle size (Electric Energy Council, 2023a). From these simple characteristics, the tool outputs predictions including CO₂ emissions produced per km, lifetime emissions produced, , in addition to a breakdown showing tonnes of emissions produced within the chronological lifecycle stages of vehicle production, and/or battery production, fuel cycle operation, and recycling practices (Electric Energy Council, 2023a).

Due to the high levels of accessibility displayed by this tool, its usability on a general consumer level can be assumed as positive. Not only does this tool require little input values, but it also only requires input values of a very basic scale, including powertrain type and vehicle size (Electric Energy Council, 2023b, p. 2), information which is highly accessible to all types of researchers or users, in order to generate some type of life cycle analysis. However, this does leave room for concern from an academic perspective as the lack of input options means that the output results only harness the ability to be generalized figures, and therefore less accurate or catered to specific contexts.

An advantage, nevertheless, is the ability to input as many vehicles as desired, essentially allowing the user to formulate their own comparison between specific automobile sizes and powertrains, rather than the tool taking one of each remaining type, whether this be ICE, PHEV, or EV, and doing this itself (Electric Energy Council, 2023b, p. 5). On similar lines, most baseline stages of vehicle

lifecycle are included, much like the AFLEET tool discussed above, such as manufacture, operation, and end-of-life (Electric Energy Council, 2023b, p. 3).

3.2.2 Conclusions – Selected tool for research

In conclusion, each of the above LCA tools provide insightful and practical information to its users, including everyday drivers, assisting in consumers making the educated choice in terms of what vehicles they purchase and operate based on environmental and economic trends associated with each technology, as well as providing critical data calculations for academic research, such as this investigation. However, one tool appears to harness capabilities more suited to the in-depth nature of this dissertation more so than its contenders which, whilst catered accordingly to the general consumer market, lack the levels of specification inputs and therefore generated outputs that this investigation considers critical.

Therefore, as per the above assessment, the IEA Life Cycle Assessment Calculator is the chosen application to be used for this research. This is due to the tool's many relevant features including input selection options, but also the outputs offered. Whilst the application provides generic inputs automatically, for example fuel consumption and economy, it allows the user to manually change these data values should the desired context not be provided within the country selection option. This will be particularly useful for this research due to the fact that New Zealand does not appear as an input option in any existing online LCA calculators, as well as giving the user the option to tailor the generated results to be as catered and as accurate as possible to suit their research needs. The ability to cater the outputs to not only show emissions per kilometre travelled but also the emissions produced over a vehicle's entire lifetime will prove incredibly beneficial to this investigation in terms of its overarching, cradle-to-grave, or cradle-to-cradle scope. In terms of this all-encompassing scope, the tool includes vehicle and/or EV battery production stages and well-to-tank phases in its results, showing outputs beyond the perspective of operations-based emissions as the sole focus.

To circulate this back to the scope of the New Zealand context, localized input values surrounding New Zealand vehicle lifespan statistics, driver behaviours, and electricity consumption of electric vehicles need to be collected to conduct further steps in addition to the usage of the IEA Lifecycle Assessment Calculator to make these lifecycle results as accurate and bespoke to New Zealand as possible.

Chapter 4

Methods

This research investigation utilized a two-step methodology approach to obtain its results. This included:

- ***Calculated results***

Results pertaining to the overall total lifecycle emissions contributions as well as emissions associated with each phase of the vehicle lifecycle were calculated through the usage of an established LCA tool.

- ***Adjustment to NZ context***

The results generated by the application were then manually refined based on New Zealand specifics, including vehicle lifetime distances travelled, purchased energy emissions factors, and electricity consumption rate or EV 'fuel economy' to make these results bespoke to the New Zealand context.

The following chapter describes each of these methods in detail, explaining the data collection sources and procedures undertaken that contributed to the final results of this research stated in the later Chapter 5.

4.0 LCA tool – Data collection

As discussed within the previous Chapter 3.2, the decision to utilize the IEA Lifecycle Assessment Calculator to conduct this research means that input values representing average New Zealand vehicle lifespans, driver behaviours, and electricity consumption rates are required to be identified and input into the online tool.. All input data values are derived from domestic sources including governmental institutions and leading renewable vehicle transitions agencies that are distinctly New Zealand-specific.

4.0.1 Input data values required

The following table displays the input values entered in the IEA Lifecycle Assessment Calculator, firstly for ICEs and then for EVs, based on the requirements of the tool in order to generate lifecycle emissions results, what vehicle type LCA they are relevant to, whether the input value is constant for all vehicle calculations or subject to change based on multiple vehicle characteristic options

(independent or controlled variable), as well as the official New Zealand sources from which these values were obtained, if applicable.

Table 2- Input data values for ICE LCA

Input requirement	Value(s) inserted	Variable type	Citation
Country/region	World	Controlled	N/A [option(s) provided for selection within tool]
Vehicle type	Petrol	Controlled	N/A [option(s) provided for selection within tool]
Fuel type	Petrol	Controlled	N/A [option(s) provided for selection within tool]
Vehicle size (kg mass)	Small (1030kg)	Independent	(IEA, 2024b, p. 2)
	Medium (1420kg)		
	Large (1870kg)		
	Pickup (1870kg)		
	SUV (1740kg)		
Average milage travelled (km/day)	29 km/day	Controlled	(MoT, 2024b)
Vehicle lifespan (years)	20 years	Controlled	(MoT, 2024a, section 7.2a)

Table 3 - Input data values for EV LCA

Input requirement	Value(s) inserted	Variable type	Citation
Country/region	World	Controlled	N/A [option(s) provided for selection within tool]
Vehicle type	BEV	Controlled	N/A [option(s) provided for selection within tool]
Vehicle size (kg mass)	Small (840kg)	Independent	IEA, 2024b, p. 2)
	Medium (1250kg)		
	Large (1380kg)		
Average milage travelled (km/day)	29 km/day	Controlled	(MoT, 2024b)
Vehicle lifespan (years)	20 years (without battery replacement)	Independent [all EVs without battery replacement to have consistent 20 year lifespan, all EVs with battery replacement to have 40 year lifespan - See section 4.0.2 for justification)	(MoT, 2024a, section 7.2a)
	40 years (with battery replacement)		
Average fuel economy/power consumption (kWh/100km)	18 kWh/100km	Controlled	(Concept Consulting Group Ltd, 2016)
BEV battery replacement	Yes	Independent	N/A [option(s) provided for selection within tool]
	No		
BEV battery range capacity (km/charge)	100km	Independent	N/A [option(s) provided for selection within tool]
	150km		
	200km		
	250km		
	300km		
	350km		
	400km		
	500km		

4.0.2 Lifespan values for the different vehicle types

The vehicle types assessed within this investigation consist of three different profiles; internal combustion engines (ICE), electric vehicles (EV), and electric vehicles that have received a battery replacement.

The input value for lifespan of ICE vehicles can be found by identifying the average age of vehicles in New Zealand when scrapped. New Zealand’s Ministry of Transport Fleet Statistics can be used to obtain this figure, recording statistics surrounding light vehicles’, both imported and ‘NZ New’, age when leaving the fleet within the latest full calendar year of 2023 (MoT, 2024, 7.2a). This data source states an average age for used light vehicles when scrapped as 20 years (MoT, 2024, 7.2a). This figure can therefore be taken and used as the age input into the IEA Lifecycle Assessment Calculator as the overall average representation for ICE vehicles in New Zealand.

When it comes to the lifespan of electric vehicles, or, in other words, the average cradle-to-grave lifetime, the methodology behind the chosen IEA Lifecycle Assessment Calculator provides

information surrounding the background figures the IEA has founded this online tool upon. Under the section 'Battery Manufacturing' within their methodology report, the IEA provides a link to the resource which they base their assumptions surrounding EV vehicle and battery vehicles upon (refer to Appendix B). This publication states that EV batteries have an approximate lifespan of 20 years (Argue, 2025). This directly reflects that of the average ICE vehicle (EECA, 2015, p. 26), with modern EV batteries designed in a way that purposefully reflects and thereby competes with the lifetime expectancies of traditional petrol cars (EECA, 2015, p. 26).

With the BEV battery designed to last an average of 20 years, without a battery replacement the car itself is also limited to this 20 year lifespan. Moreover, with the selected IEA Lifecycle Assessment Calculator following these statistics, it is therefore justifiable to also set the average lifespan of an EV, although one that has not received a battery replacement, at 20 years.

Consequently, the average life expectancy for an EV that has had the battery replaced is 40 years, with a new battery exhibiting the same original lifetime capacity of 20 years being installed, and thereby doubling the vehicle's lifespan. With an EV battery having a lifespan of 20 years, and therefore an EV with the original battery thereby also having a lifespan of 20 years, the replacement of a new battery extends this lifespan by another 20 years, giving a theoretical and logical lifespan for an EV that has undergone a battery replacement of 40 years.

By using these justifiable lifespan values of 20 years for ICEs, 20 years for EVs, and 40 years for EVs with a battery replacement, this further allows this investigation to take the 20 year lifespans for ICEs and EVs as the standard for baseline comparison between the two vehicle types when generating and analysing the cradle-to-grave results. The doubled 40 year lifespan of an EV with a replaced battery, however, provides a means of assessing the vehicle types in a way that takes on a cradle-to-cradle perspective for comparison, and allows investigation into the lifecycle emissions implications of battery replacement versus the that of the manufacturing process of a whole new car.

Table 4 - Lifespans for vehicle types

Light petrol vehicle (ICE)	Electric vehicle (EV)	Electric vehicle with replaced battery
20 years	20 years	40 years

For the purposes of this research, when conducting the LCA tool to generate results for ICEs and EVs (without battery replacement), both exhibiting the standard 20-year lifespan, the LCA assumes the form of a cradle-to-grave perspective, this representing a one-time, set lifecycle span where the vehicle(s) are produced, operated, and the eventually go on to their end-of-use. As for analysis surrounding EVs with battery replacement (lifespan of 40 years), this research then assumes this LCA as a cradle-to-cradle approach, with the presence of a battery replacement extending the lifecycle of the vehicle past its previous end-of-usage point. This plays a role in vehicle type LCA and is considered during the generation of results found by this research, which are discussed later in this paper.

4.0.3 Running the IEA Lifecycle Assessment Calculator

The tool provides outputs of CO₂-e emissions of car and or battery production, well-to-tank, and tank-to-wheel phases (each when applicable). For clarification, car and battery production refers to all emissions involved within the manufacturing process, whilst well-to-tank refers to the energy or fuel production process and all emissions involved in either the oil refinement and delivery (ICE vehicles) or the electricity generation and distribution whilst charging (EVs) (IEA, 2024, p. 5-6). Tank-to-wheel refers to the fuel consumption or combustion phase, also known operation, which is relevant to ICEs but not to EVs due to their net zero emissions in driving (IEA, 2024, p. 7).

4.2.1.2 Generating ICE results

Using the data values displayed in the table above, the IEA Lifecycle Assessment Calculator was used to generate results surrounding the emissions produced from small, medium, large, pickup and SUV sizes of ICE vehicles within New Zealand.

Generated results from the different input value combinations were inserted into the LCA tool, representing each vehicle size possibility, whilst variables including location, vehicle type, fuel type, daily milage, and lifespan were kept consistent.

Please refer to Appendix A for these raw results.

4.2.1.3 Generating EV results

Using the data values displayed in the table above, the IEA Lifecycle Assessment Calculator was used to generate results surrounding the emissions produced from different electric vehicle models within New Zealand. This included small EVs with 100km, 150km, and 200km battery ranges, medium EVs with 150km, 200km, 250km, and 300km battery ranges, and large EVs with 300km, 350km, 400km, 450km, and 500km battery ranges.

Generated results from the different input value combinations were inserted into the LCA tool, representing each vehicle size and battery range possibility, whilst variables including location, vehicle type, daily mileage, lifespan, electricity consumption economy, and no record of battery replacement were kept consistent.

Please refer to Appendix A for these raw results.

4.2.1.4 Generating results for electric vehicles including battery replacement

When calculating the results for electric vehicles that have undergone a battery replacement, the values pertaining to these vehicles found within the table above were used in conjunction with the above results generated for electric vehicles without a battery replacement (see Appendix A). In contrast to results generated for ICEs and EVs without battery replacement, lifecycle emissions for EVs with battery replacement were not generated directly through usage of the IEA Lifecycle Assessment Calculator due to the lifespan value for EVs with battery replacement used in this investigation being 40 years, and the tool allowing a maximum vehicle lifespan input of 20 years. Results for electric vehicles with battery replacement were therefore given through a combination of the results generated for EVs without a battery replacement in the table above, bearing in mind the only input needing to be changed as the lifespan of 40 years, in addition to manual calculation.

To be precise, the lifecycle emissions results pertaining to EVs without battery replacement were used to determine the lifecycle emissions results for the corresponding size and battery range combinations for EVs with battery replacement, including some additional workings based on the increased lifespan value set. Emissions results pertaining to the car production emissions were kept the same, as these are set values pertaining to a once-occurring phase within the vehicle's lifecycle that is not impacted based on the life expectancy of the vehicle. Secondly, the well-to-tank phase was multiplied by two in order to reflect the comparatively doubled lifespan of 40 years.

In addition, the battery production value generated was also kept consistent, following the methodology behind the IEA Lifecycle Assessment Calculator where it states the 'battery production' phase only includes emissions relevant to the first BEV battery produced and installed into the vehicle, with any other future replacements and their related emissions falling under the figures

generated for the 'battery replacement' phase (IEA, 2024, p. 3-4). The battery replacement value is therefore added, which was identified through the tool's methodology statement where emissions in this phase are defined as separate from the original emissions pertaining to the 'battery production' phase due to "process and technology improvements: reduced CO₂ intensity of electricity and heating, 30% increased energy density, and 20% of the cathode active material sourced through recycling" (IEA, 2024, p. 4).

All of these steps and values were therefore added together in order to give the total lifecycle emissions for EVs of each size and battery combination for a 40-year vehicle lifespan timeframe.

Please refer to Appendix A for these raw results.

4.0.4 Adjustments to fit the New Zealand context

With the IEA Lifecycle Assessment Calculator, or any existing vehicle lifecycle tool, failing to provide an input option for the geographic location of New Zealand, the lifecycle emissions results surrounding the well-to-tank, or energy production phase, and therefore the over total lifecycle emissions figure generated, for electric vehicles is not entirely accurate to the New Zealand context desired by this research. It should be noted that this need for adjustment is only relevant to the lifecycle emissions results generated for electric vehicles, with those ICE results generated by the tool remaining accurate and reliable due to the omission of electricity consumption rates or other New Zealand-specific data that impacts these figures and therefore are excluded from needing any further refinement.

Despite still being accurate in a general sense, it is important that this investigation goes beyond the generalized, global scope and provides accurate and reliable insight into the specifics of electric vehicles in New Zealand, which will differ, even if not by much, to the emissions factors and electricity consumption rates found in other countries of the world that make up the background assumptions of the outputs generated by the LCA tool.

Localized and formal data surrounding average vehicle end-of-life odometer readings and the latest national emissions factors need to be collected. By identifying these New Zealand-specific statistics, further steps, as an addition to the usage of the IEA Lifecycle Assessment Calculator, can be conducted to adjust the lifecycle results of electric vehicles generated by the tool to be as accurate and bespoke to New Zealand as possible.

4.2.2.1 Data for further refinement

New Zealand-specific data required in order to further refine these results include:

- I. The average total lifetime distance travelled by the vehicle (i.e. the average odometer reading taken at the end-of-life or scrappage stage in kilometres)
- II. New Zealand purchased energy emissions factor (i.e. annual average electricity used in the latest recorded year of 2024 in kgCO₂-e)
- III. The average electricity consumption rate of electric vehicles in New Zealand (electric vehicle electricity/'fuel' economy)

The average total lifetime distance travelled by New Zealand vehicles can be determined by taking the New Zealand average daily driven distance of 29km/day (MoT, 2024) and multiplying this in relation to the average vehicle lifespan of 20 years (Argue, 2025 and EECA, 2015, p. 26). With the average light passenger vehicle in New Zealand travelling 29km of travel per day for a life expectancy of 20 years, the vehicles odometer reading at the end-of-life phase would therefore equate to 211,700km. This is interpreted as the lifetime distance travelled by the vehicle, and is the figure that will be used as an input value when adjusting the electric vehicle lifecycle emissions results produced by the IEA Lifecycle Assessment Calculator in order to refine them to the New Zealand context.

This can also be cross-referenced by accessing the data spreadsheet available under the Ministry of Transport's Fleet Statistics Open Data Tool (MoT, 2024). Section 7.3de of the Excel spreadsheet provided by this Ministry of Transport-owned online application shows a collection of 'Last odometer reading of scrapped vehicles', as well as an overall average, leaving the fleet in 2024, with data updated as of October/November 2025 (MoT, 2024). With these vehicles being scrapped and therefore exiting the overall fleet makeup of private vehicles in New Zealand, the odometer reading can be simply interpreted as the vehicle's total distance travelled throughout its entire lifetime, and therefore gives the figure needed. Section 7.3de of the latest 2023 Fleet Statistics records the average odometer reading of light passenger New Zealand vehicles when being scrapped or leaving the fleet as 212,180km (MoT, 2024).

Additionally, the Energy Efficiency and Conservation Authority (EECA) published a final report titled 'Lifecycle Assessment of Electric Vehicles' in November of 2015 (see section 3.0.4), with this report detailing an in-house study that "nominates a passenger car operational life of 210,000km for all vehicles" (EECA, 2015, p. 26).

Both of these external figures, from both the Ministry of Transport and the EECA, are similar to the average lifetime vehicle distance value of 211,700km determined by the investigations conducted this research, thereby further justifying its reliability and usage within refining calculations.

When it comes to EVs that have undergone a battery replacement, and therefore have an extended lifespan of 40 years within the calculations of this research, the total lifetime distance travelled is therefore also doubled to align with this methodology. This gives EVs with a replaced battery a final odometer reading of 423,400km.

As for the electricity economy rate of electric vehicles in New Zealand, this can be taken from the input data values collected when originally running the IEA Lifecycle Assessment Tool, with this being 18 kWh/100km (Concept Consulting Group Ltd, 2016, p. 41). This is an average electricity economy rate used across all EV sizes within this research investigation.

As for the purchased energy emissions factor, this can be located through the Ministry for the Environment's Measuring Emissions Guidance 2025 database (MfE, 2025). The 'Emissions Factor Workbook Using Data and Methods from calendars years between 2012 and 2024' shows the 'Purchased energy emissions factors – annual average', with electricity used in the recent year of 2024 recorded as 0.101 kgCO₂-e. This figure represents the current emissions factor for New Zealand electricity and therefore can be used in the further refinement of these electric vehicle lifecycle emissions results through the relevance it holds to the electricity supply to and consumption rate/economy of electric vehicles in New Zealand.

4.2.2.2 Refining calculations

With the need for refinement being only relevant to the results generated for electric vehicles, the well-to-tank lifecycle emissions value produced by the IEA Lifecycle Emissions Calculator, and therefore the total lifecycle emissions figure, for each vehicle calculation are what require adjustment. Other emissions numbers generated, such as those pertaining to car production, battery production, or battery replacement phases, are not impacted and remain applicable to the New Zealand context.

Firstly, the well-to-tank, or energy production, emissions figure generated by the tool equates to 13.5tCO₂-eq/vehicle for electric vehicles with no battery replacement (and therefore a 20 year lifespan) and 27tCO₂-eq/vehicle for electric vehicles with battery replacement (40 year lifespan). In order to calculate the new well-to-tank figure and adjust the overall lifecycle emissions of the electric vehicles, a new equation that takes the average total lifetime distance travelled by the vehicle

(211,700km or 423,400km), multiplied by the electricity consumption rate (18kWh/100km), and further multiplied by the emissions factor value (0.101CO₂-e/kWh). After this three step multiplication, the result must be then divided by 100 to convert to kgCO₂-e and then divided by 1000 to convert to the unit of tCO₂-eq/vehicle consistent with this research.

New well-to-tank value - EVs (20 year lifespan/without battery replacement):

$$\frac{(211,700 \times 18 \times 0.101)}{100} = 3848.706 \qquad \frac{3848.706}{1000} = 3.848706$$

The new and refined well-to-tank figure for electric vehicles *without* battery replacement is therefore 3.8tCO₂-eq/vehicle.

New well-to-tank value - EVs with battery replacement (40 year lifespan):

$$\frac{(423,400 \times 18 \times 0.101)}{100} = 7697.412 \qquad \frac{7697.412}{1000} = 7.697412$$

The new and refined well-to-tank figure for electric vehicles *with* battery replacement is therefore 7.7tCO₂-eq/vehicle.

By taking each of the total lifecycle emissions figures calculated for all EVs involved in this research, subtracting the previous well-to-tank figure of either 13.5tCO₂-eq (for EVs without battery replacement) or 27 tCO₂-eq (for EVs with battery replacement) from each, and then adding on the new well-to-tank figure, 3.8tCO₂-eq or 7.7 tCO₂-eq, the new and refined total lifecycle emissions value for each electric vehicle is given.

[Previous total lifecycle emissions – previous well-to-tank value (13.5tCO₂-eq or 27tCO₂-eq)]

+ new well-to-tank value (3.8 tCO₂-eq/vehicle or 7.7 tCO₂-eq/vehicle)

= NZ bespoke total lifecycle emissions/vehicle

All finalized results, after conducting these necessary adjustments, for vehicles within both EV circumstances, as well as results pertaining to ICEs, are presented within Chapters 5.1 and 5.2.

Please refer to Appendix B for a full list of all calculations conducted.

4.1 Data analysis

4.1.1 Assumptions and limitations

The rise in renewable electricity, fluctuating distances travelled by New Zealand drivers, and constant automotive engineering improvements means that these values are inevitably vulnerable to frequent change. In the same way that set yearly figures can also fluctuate, so can averages when extreme variables experience change. Similarly, average figures were taken from only official sources and the most recent data collection and provision sources possible in order to avoid any influencing discrepancies.

Due to the modern nature of the topic, assumptions surrounding the determination of data taken from specific, current time periods could not be avoided. It is important to make clear that this is inevitable, with new data emerging continuously from governmental and institutional sources surrounding the uptake of EVs and ICEs, impacts of both vehicle types on emissions, yearly emissions factors for purchase energy, and distances travelled by drivers. The most recent and most reputable data available was used in this investigation.

Limitations of the IEA Lifecycle Assessment Calculator include the omission of lifecycle emissions outputs for electric vehicles in the sizes of pickup and SUV. This is due to the fact that the tool does not recognize any existing pickup or SUV-sized electric vehicles with an electricity consumption rate of 18kWh/100km, or the New Zealand average. This was made aware and taken into account going into this investigation. Whilst the tool recognizes this for all other size EVs, small, medium, and large, this does mean this research investigation therefore has lifecycle emissions results for ICE vehicles in the pickup and SUV size, but has no data for EVs in these two, specialized sizes. Because of this, the lifecycle emissions results for pickup and SUV-sized ICEs are not included within the following results section of this research due to this discrepancy and in order to keep the results for both ICE and EVs in a uniform and consistent standard for comparison, using only small, medium, and large variables for each. The tool also ends with the life cycle phase of operation, thereby omitting the end-of-life or recycling phase, meaning this area of assessment is excluded from results generation and therefore the analysis.

Another notable point includes the place-based origins of the emissions generated throughout each of the vehicles' lifecycle phases, and how this is used to interpret the data collection and results generated. As recorded within section 7.2a 'Average age of light fleet used imports/New when scrapped, by year' of the Ministry of Transport Fleet Statistics Open Data Tool, it is not only 'NZ New' vehicles that experience operation and consequential scrapping domestically, but that rather many cars are imports that have experienced a usage outside of the geographical area of New Zealand.

Specifically, with a large proportion of New Zealand's light vehicle fleet being imported mid-life from countries such as Japan, many vehicles counted within the end-of-life disposal phase will have previous emissions contributions correlating to the earlier years of the vehicle lifecycle, such as production and even tank-to-wheel operation, prior to arrival within New Zealand (Stats NZ, 2021). This research calculates the total life cycle emissions of each vehicle type irrespective of where these occur geographically.

Certain controlled input variables, as well as the generated and refined results of this experiment are therefore representative of the lifecycle emissions of each vehicle type irrespective of its country of origin. Both vehicle types, ICE and EV, include the possibility of previous emissions contributions outside of the New Zealand context, meaning, whilst this is something to take into consideration, and a potential area for future examination, this does not impact the results produced within this research. Although this research focuses on New Zealand vehicles, the scope pertains to lifecycle emissions of each vehicle, no matter the country of manufacture or previous usage.

Chapter 5

Results

Results of this research were obtained through a combination of outputs generated through the foundational workings of the IEA Lifecycle Assessment Calculator used, as per the New Zealand specific input values and subsequent adjustment calculations detailed within the previous section, as well as the additional calculations taken in order to produce figures bespoke to the New Zealand context.

These results cover those of both vehicle types (ICE and EV), in all sizes including small (1030kg), medium (1420kg), large (1870kg), pickup (1870kg), and SUV (1740kg) ICES and small (840kg), medium (1250kg), and large (1380kg) EVs, battery ranges (100km, 150km, 200km, 250km, 300km, 350km, 400km, 450km, 550km), and battery replacement (replaced or not replaced) combinations (IEA, 2024).

As per the lifespan data used in this investigation (see Chapter 4.1.2), all results generated for ICE lifecycle emissions are expressed in a 20 year period. Results for EVs without battery replacement also follow the 20 year period, whilst results for EVs with a battery replacement are over a 40 year lifespan.

The total lifecycle emissions of each vehicle type are shown in section 5.0, and are then broken down into each contributing lifecycle phase in section 5.1. Results in relation to the impact of EV battery replacement, and therefore extended vehicle lifespan, are then shown in section 5.2. Finally, section 5.3 takes the results shown within these graphs and answers the research questions surrounding the most emissions-efficient vehicle type and/or size, and how this relates to the idea vehicle types for NZ drivers and households in relation to meeting emissions reduction goals.

All results are representative of the lifetime or complete lifecycle of the vehicle, and are expressed as tonnes of carbon dioxide equivalent per vehicle (CO₂-eq/vehicle).

5.0 Total lifecycle emissions comparisons

The following figures show the total lifecycle emissions produced by each vehicle type (ICE and EV) in relation to vehicle size. With there being various battery range options per weight class for EVs, each graph is accompanied by a colour-coded legend pertaining to these different options.

From these results displayed below, it is evident that as the size of the vehicle, both ICE and EV, increases, the lifecycle emissions also show a corresponding increase. In addition, ICE vehicles, no

matter the size, consistently show significantly higher levels of total lifecycle emissions when compared to EVs. All sizes of EVs show comparatively less amounts of lifecycle emissions, when against ICEs, with these total lifecycle emissions increasing only slightly in proportion to the battery range capacity. In other words, the larger the EV battery range, the higher the lifecycle emissions, despite this increase being rather small.

5.0.1 Results for small-sized vehicles

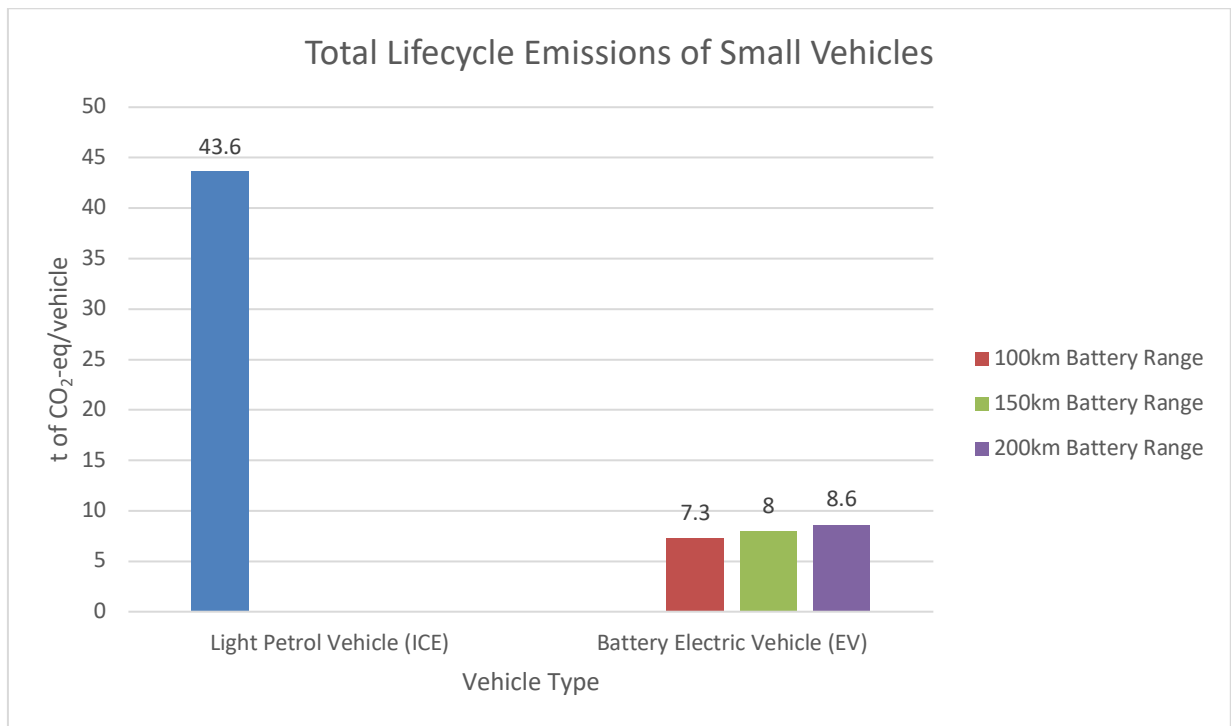


Figure 1 - Total LCA results for small-sized vehicles

5.0.2 Results for medium-sized vehicles

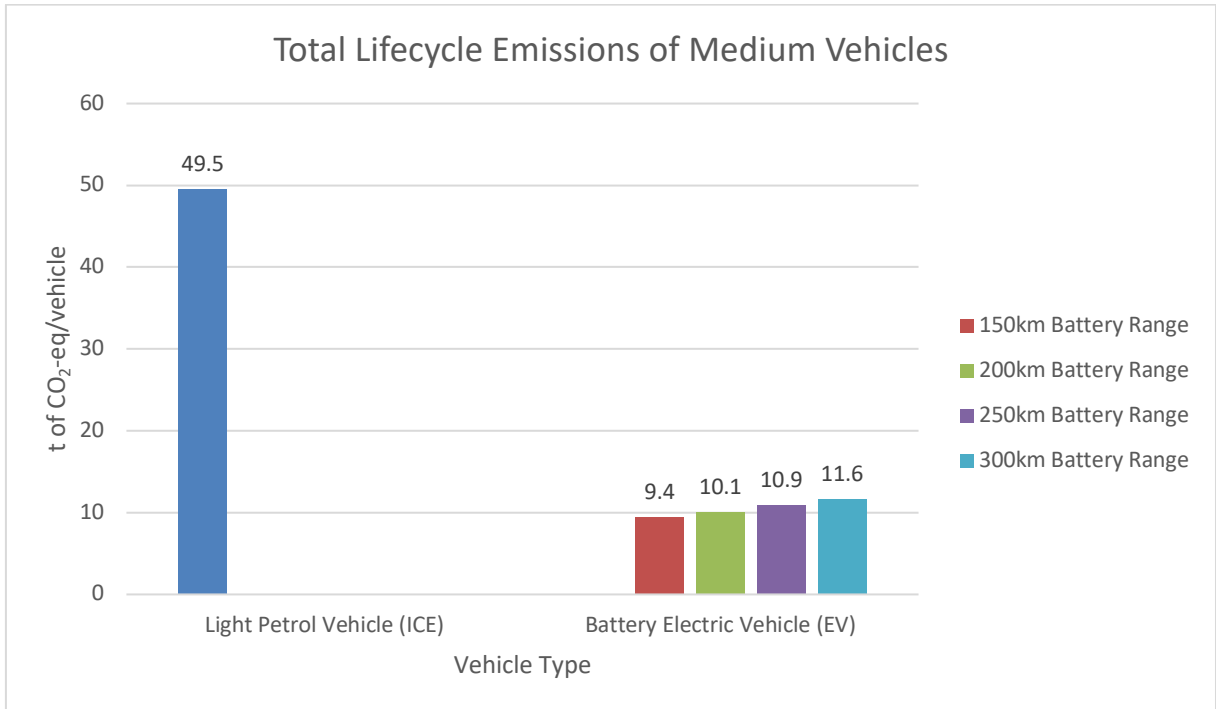


Figure 2 - Total LCA results for medium-sized vehicles

5.0.3 Results for large-sized vehicles

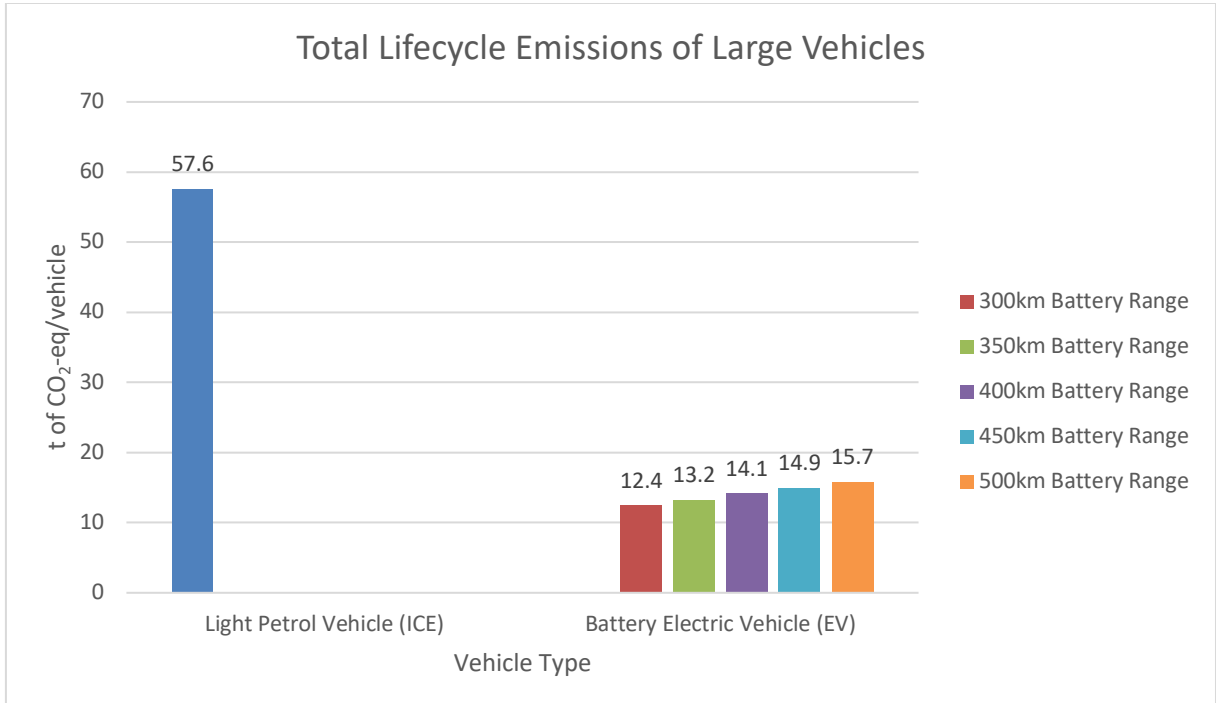


Figure 3- Total LCA results for large-sized vehicles

It is evident from each of the graphs above that emissions contributions from ICE vehicles outweigh those of EVs largely on a total life cycle emissions basis. This is a consistent observation for all vehicle

size classes and even all battery range capacity options for EVs. This is due to the differences in emissions pertaining to certain life cycle phases for each vehicle type and size, as shown within the following section below.

Additional observations include the slight proportionate increase in EV total life cycle emissions as the size of the battery range capacity increases. This is due to larger battery range capacities corresponding to larger batteries, therefore requiring more energy to manufacture and producing more emissions as a result. Continued discussion surrounding these emissions pertaining to the production phase of these vehicles is also found below.

5.1 Lifecycle phase emissions by vehicle type and size

The following figures show the emissions of each lifecycle phase for each vehicle type and size. This includes ICE vehicles with a lifespan of 20 years and the corresponding standard of comparison of an EV without a battery replacement, also having a lifespan of 20 years.

From these results displayed below, it is evident that, for ICE vehicles, a larger vehicle size equals larger emissions contributions in all phases of the vehicles lifecycle. For instance, as expected, car production emissions increase proportionately to the size of the vehicle being manufactured, but the well-to-tank, also known as energy production, and the tank-to-wheel, or fuel consumption, emissions also rise in correlation to vehicle size. This is due to larger vehicles containing larger engines and requiring more fuel/energy to travel certain distances.

In contrast, the well-to-tank emissions for EVs shows no change throughout the results, meaning that EVs of all sizes share the same consistent emissions contributions of 3.8tCO₂-eq/vehicle no matter the size or battery range capacity of the vehicle. This is due to the fact that all EVs, no matter the size of the vehicle or battery range capacity, are assumed to consume the same amount of electricity per kilometre travelled throughout the course of their lifetime, therefore leading to a value that is consistent for all EVs. Other results include the consistency in car production phase emissions contributions in correlation to vehicle size. For example all small EVs, no matter the battery range capacity, show emissions contributions of 2.1tCO₂-eq/vehicle for this manufacturing phase of the lifecycle, with the same consistency of 3.31tCO₂-eq/vehicle showing for medium-sized EVs and 3.61tCO₂-eq/vehicle for large EVs. Battery production, however, does prove to change for all EV sizes and battery range capacities.

5.1.1 Light petrol vehicle (ICE) lifecycle phase emissions

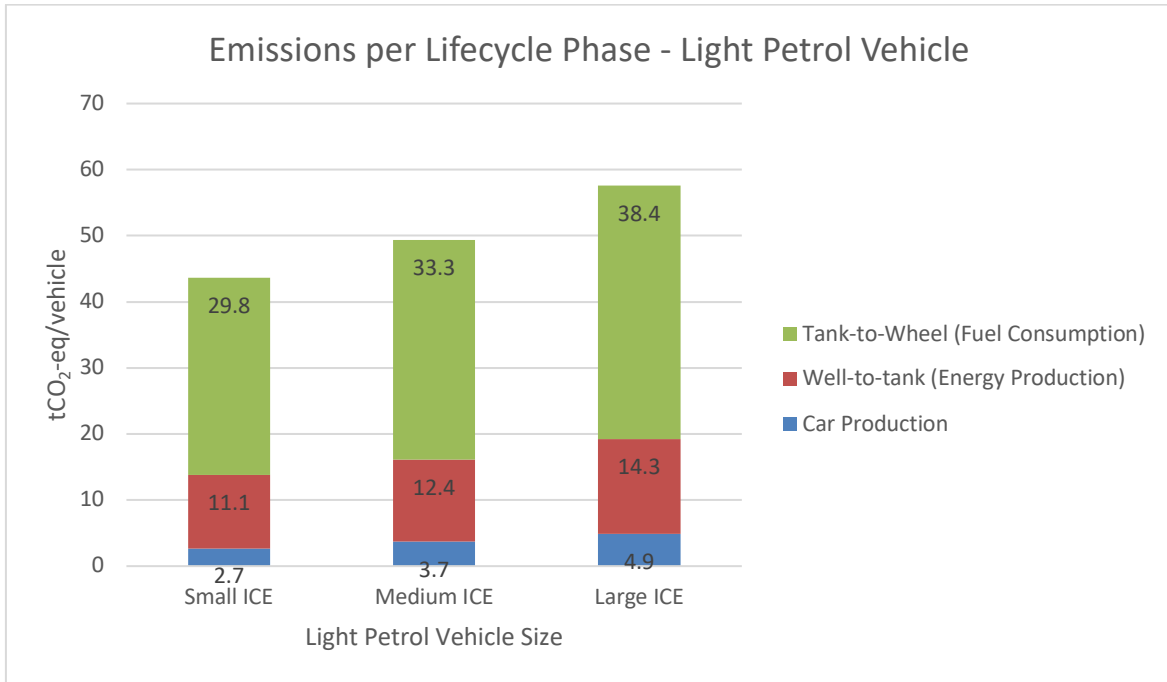


Figure 4 - LCA phase results per ICE size

5.1.2 Battery electric vehicle (EV) lifecycle phase emissions

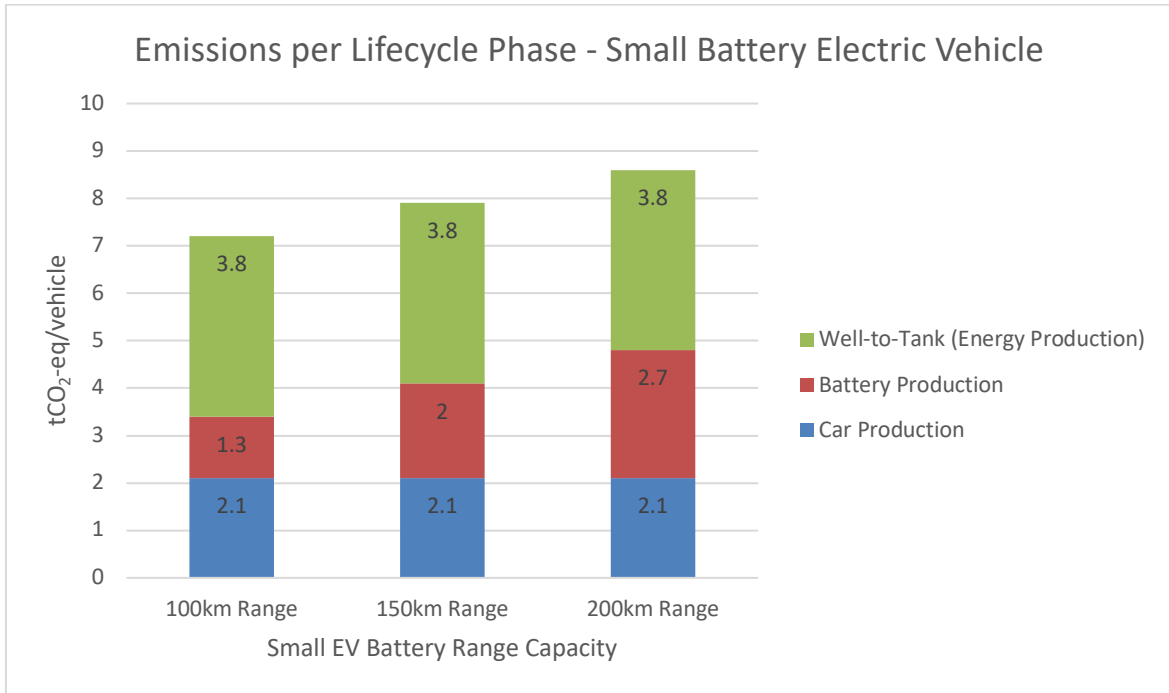


Figure 5 - LCA phase results for small EVs

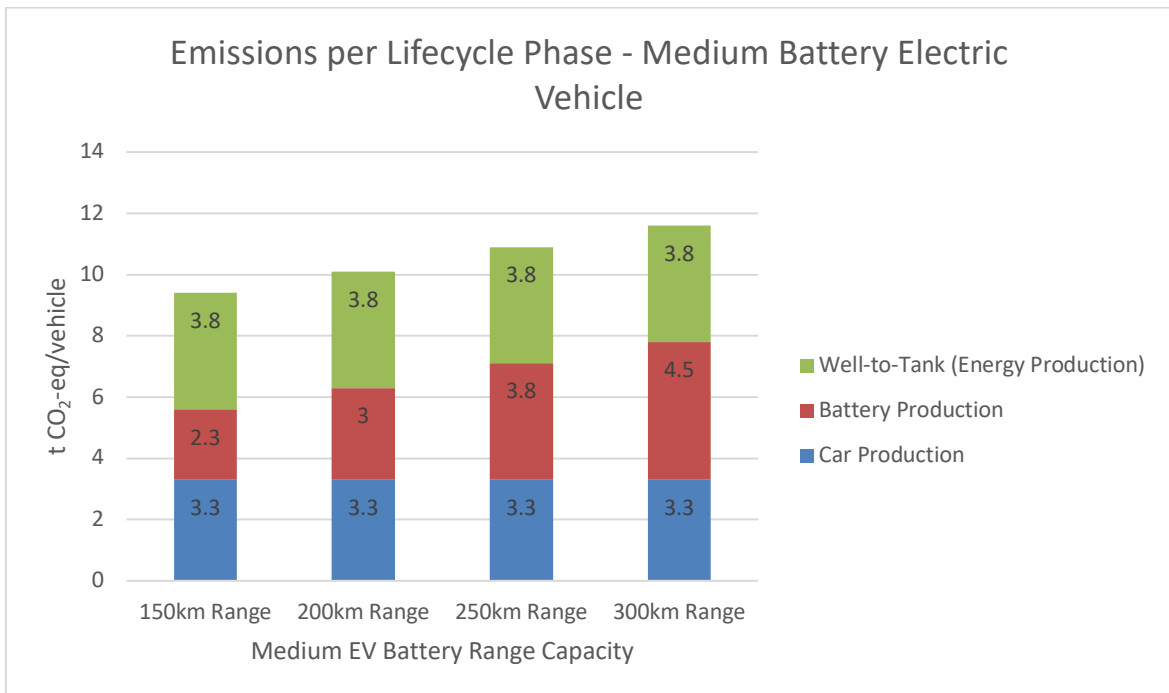


Figure 6 - LCA phase results for medium EVs

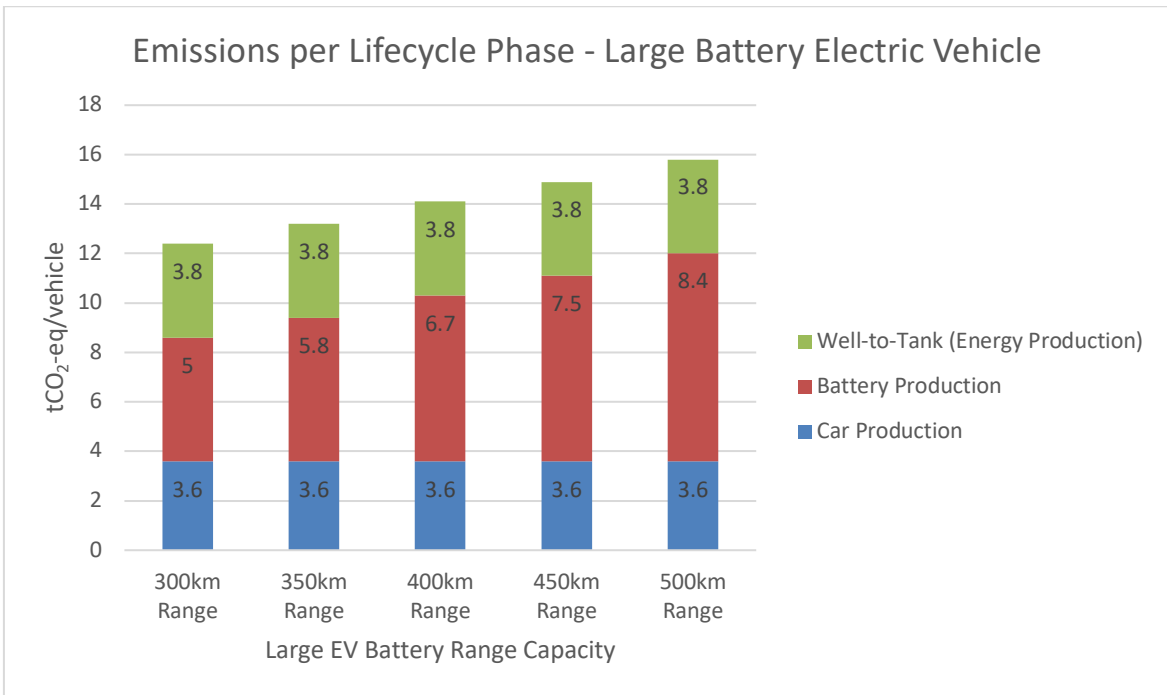


Figure 7 - LCA phase results for large EVs

5.2 Lifecycle emissions implications of EV with battery replacement

With EVs also having the ability to replace the battery, and therefore extend the original standard of comparison of a 20 year lifespan to 40 years, it is important to also consider this within calculations of this investigation and provide results surrounding this. Section 5.2.1 shows the emissions contributions per lifecycle phase for EVs with battery replacement as a breakdown based on this 40 year lifespan. In addition, section 5.2.2 shows the total lifecycle emissions generated by EVs both with and without a battery replacement, including the emissions corresponding to the different lifecycle phases, by presenting the two EV types in uniform lifespan of 20 years (achieved by halving the values generated for EVs with battery replacement/40 year lifespan) for comparison.

5.2.1 Battery electric vehicle (EV) with battery replacement lifecycle phase emissions

Lifecycle phase results involve a breakdown of the total lifecycle emissions of the three sizes of EVs with a battery replacement, as vehicles with a 40-year lifespan. These figures show the emissions contributions corresponding to the individual stages of car production, battery production, well-to-tank, tank-to-wheel, and battery replacement that constitute the total lifecycle emissions of the vehicle.

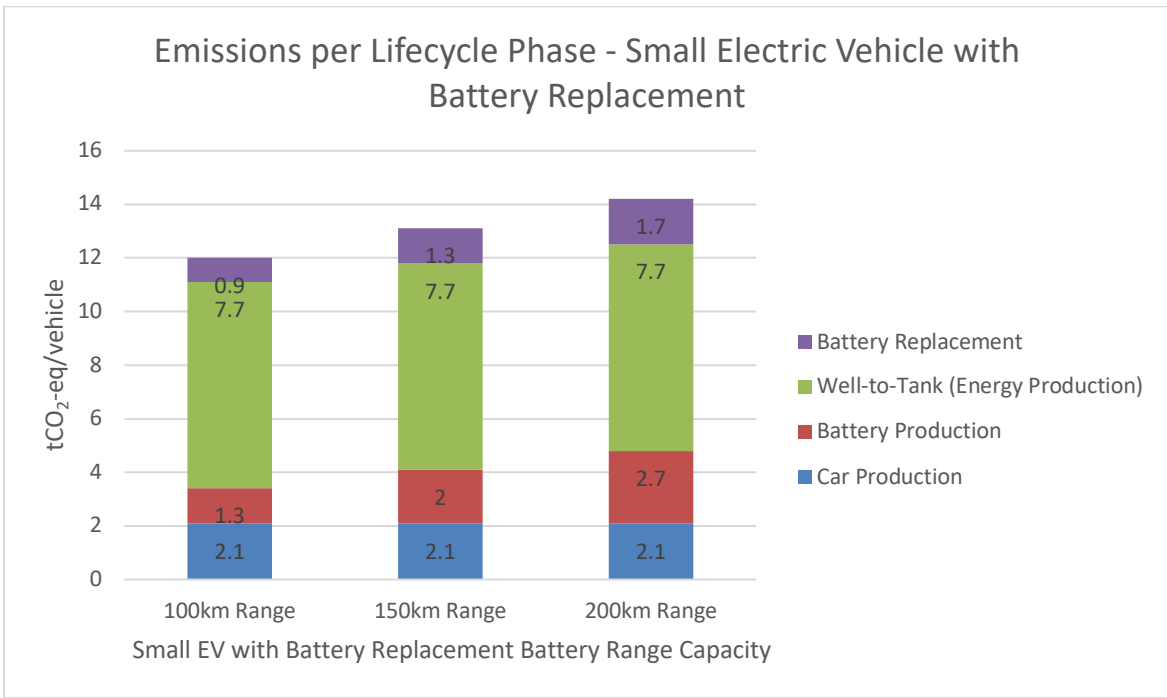


Figure 8 - LCA results for small EVs with battery replacement

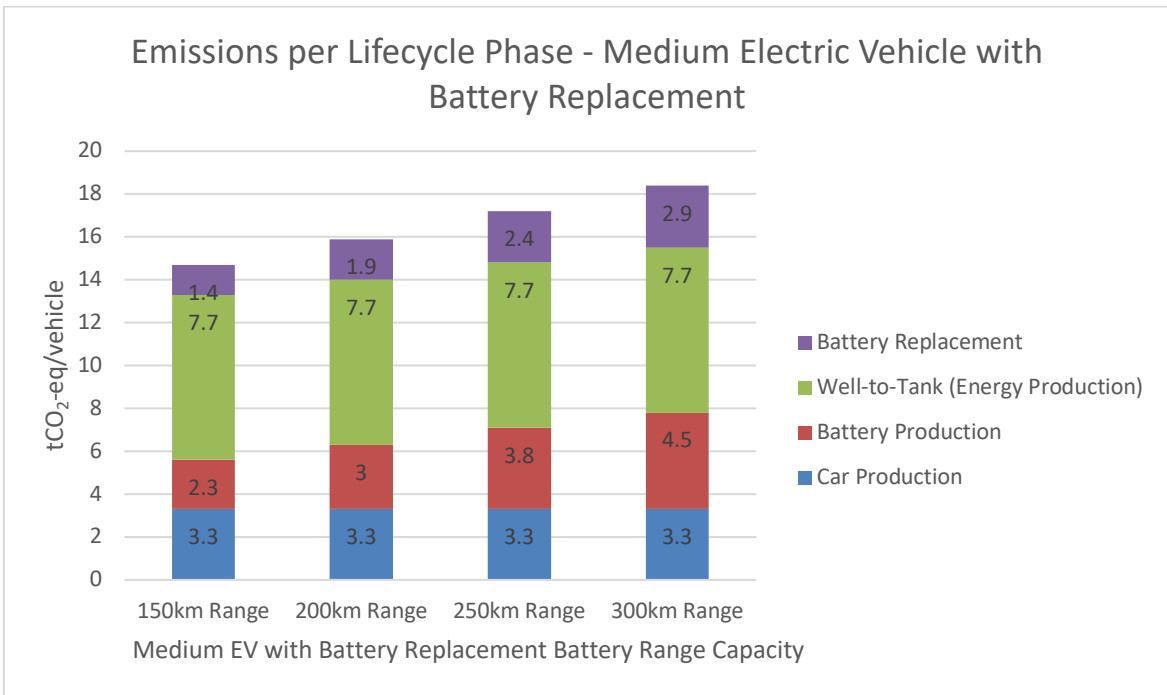


Figure 9 - LCA results for medium EVs with battery replacement

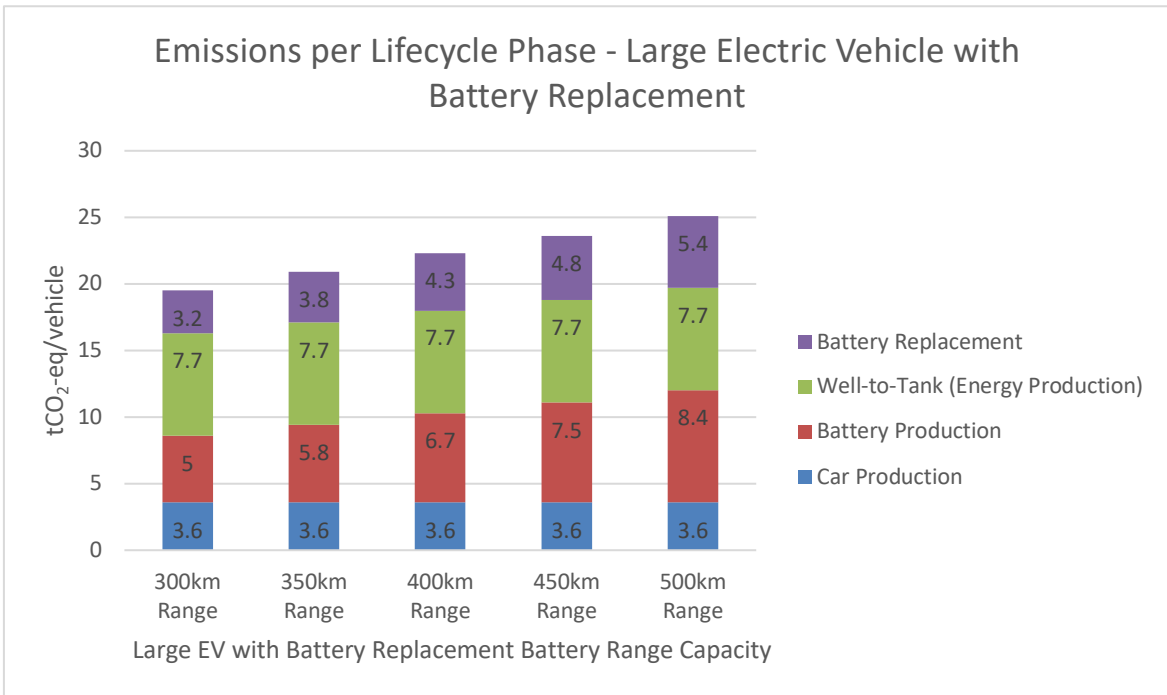


Figure 10 - LCA results for large EVs with battery replacement

As displayed by these figures above, results show that, similar to an EV without battery replacement (or a 20-year lifespan), the well-to-tank emissions contributions of all vehicles with a battery replacement (40-year lifespan), no matter the size, is consistent at 7.7tCO₂-eq/vehicle. Furthermore, this equates to twice 3.8tCO₂-eq/vehicle, or the well-to-tank emissions for EVs without a battery replacement, due to the doubling of the vehicle lifespan through battery replacement. Car and battery production emissions corresponding to the different vehicle sizes are consistent with those of EVs without battery replacements. The introduced phase of battery replacement, however, increases the overall lifecycle emissions of the vehicle, with emissions pertaining to this phase increasingly proportionately alongside an increase in vehicle size.

5.2.2 Comparison of EVs without versus EVs with battery replacement – Emissions per Kilometre

The following results contain a comparison of EVs, of all three sizes, with and without battery replacement from both a total lifecycle emissions and lifecycle phase basis. Results for both EV types, or those with and those without a battery replacement, are compared from the uniform standard of a 20 year lifespan. This is due to the fact that an EV without a battery replacement uses the standard lifespan of 20 years, whereas an EV that has undergone a battery replacement is used with an extended lifespan of 40 years (see Chapter 4.1.2). The results for EVs with battery replacement (40 year lifespan) are kept accurate by simply halving these values in order to match the standard of comparison of a 20 year lifespan.

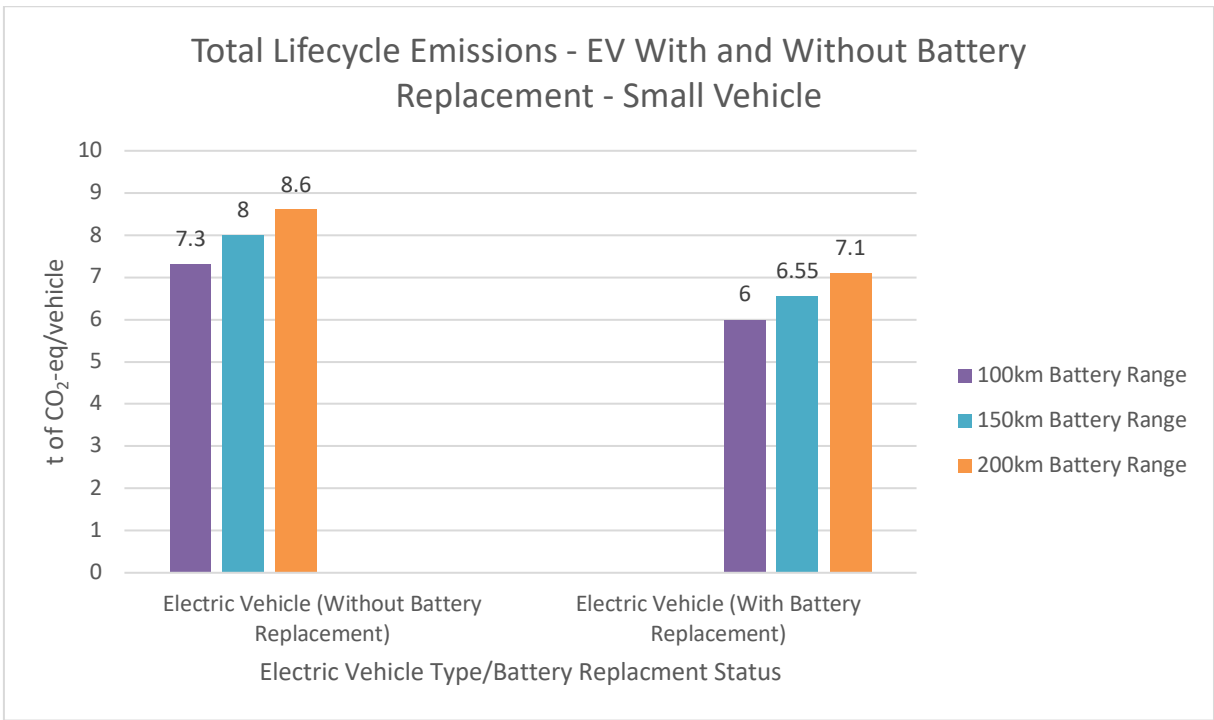


Figure 11 - Total LCA emissions - EV with vs EV without battery replacement - small

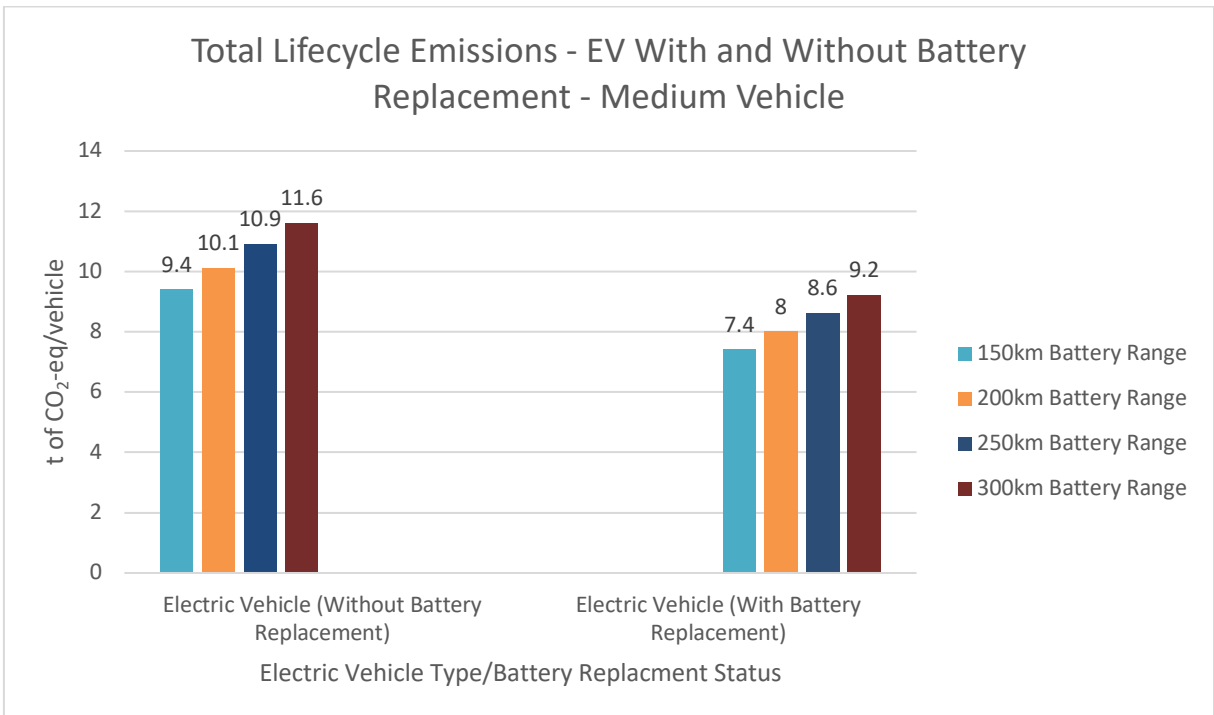


Figure 12 - Total LCA emissions - EV with vs EV without battery replacement - medium

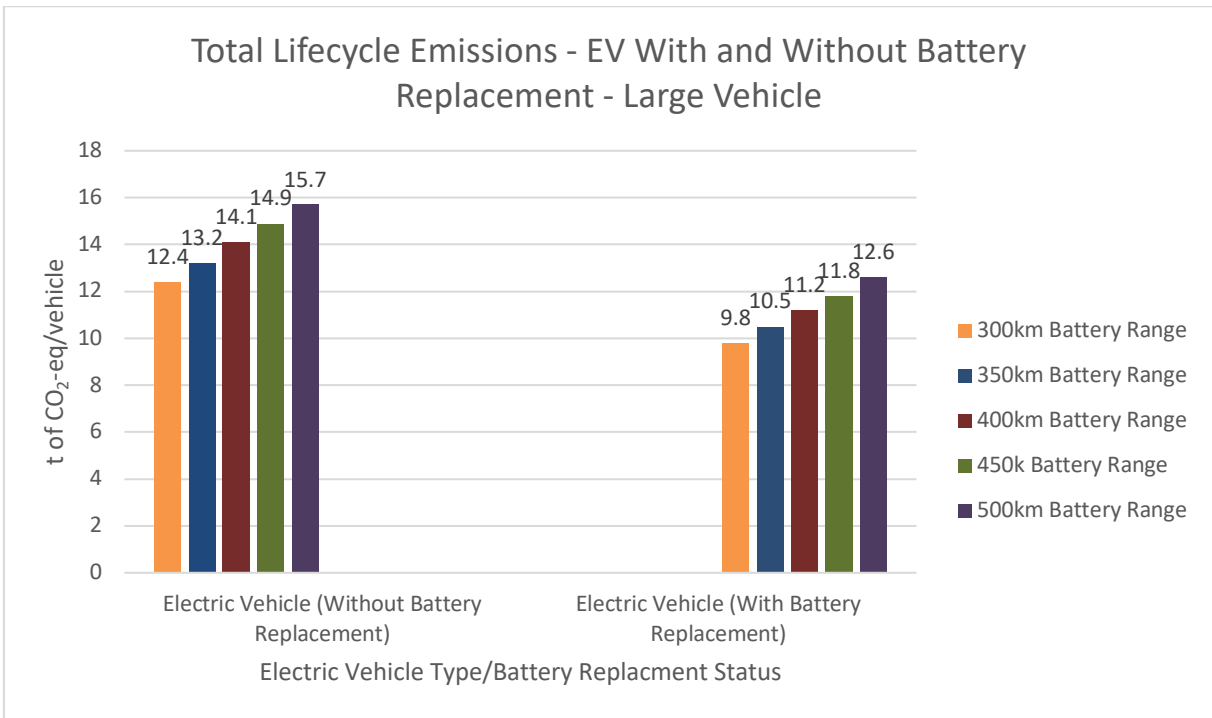


Figure 13 - Total LCA emissions - EV with vs EV without battery replacement - large

5.3 Addressing the research questions

The above findings provide the quantitative emissions data, both from an overall lifetime emissions perspective as well as on a phase-to-phase scope, required to answer the first and second research questions stated in Chapter 1.1.

- 1) What vehicle type and/or size shows the lowest projected lifecycle emissions across its lifetime?
- 2) How do the ways in which New Zealand drivers use their vehicles effect the lifecycle emissions impacts and emissions reduction capabilities of different vehicle types?

5.3.1 Vehicle type with the lowest emissions-based lifecycle impact

The results above indicate that electric vehicles are the more sustainable option of private light vehicle transportation and ownership for drivers within the New Zealand context. From a total lifecycle emissions perspective, EVs of all sizes and battery range capacities prove to contribute less emissions than that of any corresponding ICE. ICE vehicles show considerable emissions contribution quantities in every phase of the lifecycle, including higher well-to-tank (energy production) emissions as well as the addition of tank-to-tank (fuel combustion or operations-based) emissions not relevant to EVs. Reasons for ICEs corresponding to higher well-to-tank results derives from the fact that

emissions from oil extraction, refining, and delivery of these are higher than that of the electricity generation and transmission (well-to-tank) required for an EV.

Alternatively, EVs across all size categories display higher levels of emissions focused within the earlier stages of the lifecycle. These outweigh the manufacturing emissions of their ICE counterparts due to the increased need of materials required for EV battery productions. For instance, the car production phase of a small ICE corresponds to larger emissions contributions compared to a small EV due to the car production phase of an ICE also including the emissions pertaining to the manufacturing of the internal combustion engine, something which is not relevant or involved in the production of an EV. However, the emissions pertaining to the production of the EV battery are much larger in comparison, therefore leading to a larger production emissions result. Therefore, operation proportionate to these early on-set emissions of these vehicles is necessary in order to ensure a successful payback rate. Precisely, New Zealand EV owners need to drive their vehicles on a frequent basis in order to ensure that the sustainability benefits of these cars are actually reached. With EVs showing high initial emissions within the lifecycle and then contributing zero in the tank-to-wheel phase, the higher the distanced travelled throughout the vehicle's lifetime means these early emissions will be compensated for. This is the key to EVs being more environmentally successful, in terms of greenhouse gas emissions throughout the investigated lifecycle phases, over ICEs.

Moreover, with smaller EVs contributing proportionately smaller emissions in lifecycle areas including car production, battery production, battery replacement, and, of course, net zero emissions within operation phases, these specific vehicle types will achieve this payback point faster through frequent usage rather than larger EVs which have a higher initial emissions quota to override.

EVs that have undergone a battery replacement prove to contribute sustainable lifecycle emissions through the way in which they extend the average lifespan of the vehicle. Despite requiring additional emissions in order to replace the EV battery, these emissions are less than that of the original battery manufacturing contributions, due to involving the recycling of materials, rather than generating an entirely new battery. In other words, whilst the replacement of a battery adds additional emissions of the vehicle, the lifespan is extended (thus total lifecycle emission are reduced), and this is comparatively far more emissions-friendly than the emissions associated with manufacturing an entirely new replacement vehicle, or even that of an ICE counterpart.

Considering the above, this makes small-sizes EVs the lowest emissions option on an LCA basis for private light vehicle transportation and ownership in New Zealand. This is due to a combination of reasons including all EV types showing less total lifecycle emissions contributions than any ICE type,

small EVs having lower manufacturing emissions within the early stages of the lifecycle compared to other alternative EV types and sizes, and the ability to therefore reach and override this compensation point faster through frequent usage. Moreover, replacing the battery in these smaller-sized EVs when required will further enhance the sustainability of this vehicle by not only extending the lifecycle but also through choosing to add a minimal number of additional emissions, concentrated around cathode recycling and technological improvements for less CO₂ intensity of the new battery (IEA, 2024, p. 4), instead of the emissions contributions associated with opting to manufacture an entirely new vehicle unit.

5.3.2 Ideal vehicle types and ownership combinations in relation to driver behaviour

Whilst the results above show small-sized EVs as the ideal vehicle type in terms of emissions reduction and sustainability, this specific type and size of vehicle will may not be able to fit the needs and activities of all New Zealand drivers. Due to the hypothetical nature of this research question, New Zealand homes can be assumed to typically contain two cars for every household, meaning that families choose to own two separate vehicles that each fit different purposes. The most common family household combination can be assumed as one smaller-sized vehicle used most frequently accompanied by one larger-sized vehicle used only on occasional when needed.

Using the results in section 5.0 above, an analysis of the lifecycle emissions impacts of each of the vehicle combinations was undertaken in order to determine the ideal vehicle type/size split for the common NZ household context.

Each potential scenario combination consists of one large and one small car, with the two different type options of ICE or EV, with the average daily distance travelled by New Zealand drivers being 29 km/day, and a two-car household opting to utilize one vehicle more frequently and reserving the other for special purpose travel. One car in each mode split represents 75% of the average daily milage travelled by the household, this being 21.8km/day, and the other representing a distance travelled of 25% of the daily milage, or 7.2km/day. For the purpose of this research, the hypothetical data figures surrounding this distance travel split for a two-car family household scenario is hypothetical, based on a 25:75 division. Data to demonstrate this, however, could be found within WOF data pertaining to vehicle registrations within New Zealand if this household analysis was to be continued further than the bounds of this dissertation.

The average battery range capacities pertaining to small and large-sized EVs were used to represent the EVs within these scenarios, these being 100km battery range for small EVs and 300km battery

range for large EVs. Reasoning behind these chosen battery range values revolves around the input options available within the IEA Lifecycle Assessment Calculator, with 100km battery range being the baseline option for small-sized EVs, and 300km being the baseline option for larger-sized EVs (IEA, 2024a).

Household vehicle split – Scenario 1:

The following scenario is based on the combination of a household owning two vehicles, one being a small EV which is driven most frequently, and the other being a large ICE, driven less frequently.

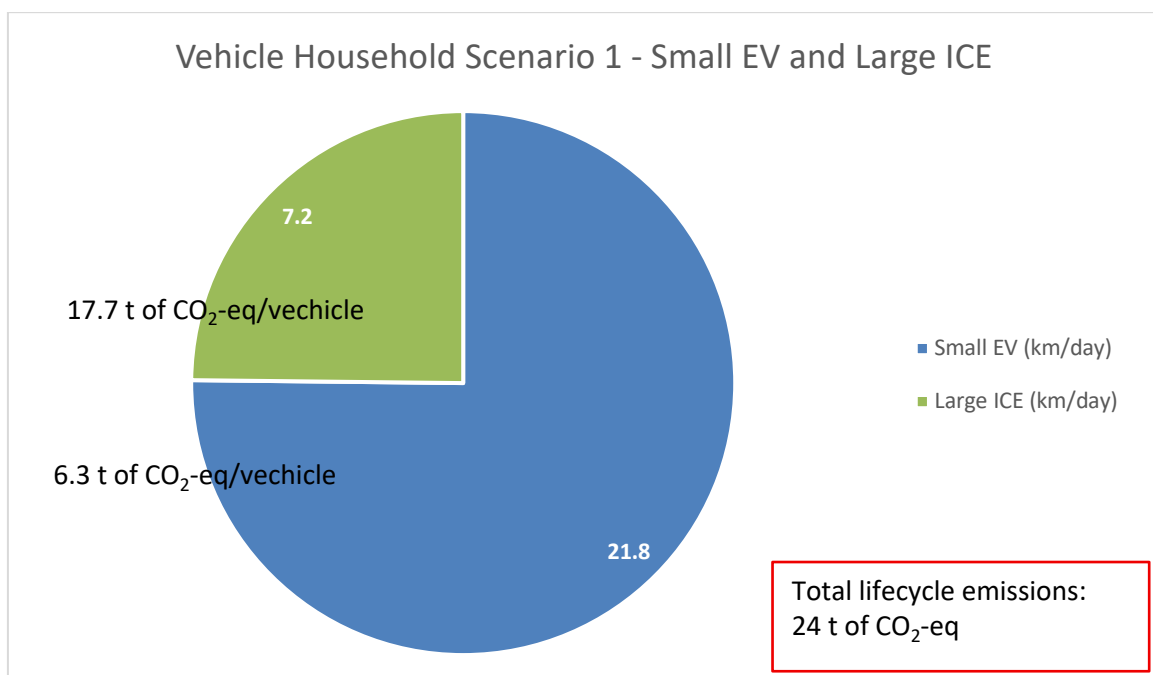


Figure 14 - Vehicle household split - Scenario 1

As evident within the figure above, a small EV travelling 75% of the 29km/day total daily average, or 21.8km/day would produce lifetime emissions of 6.3 t of CO₂-eq/vehicle. In addition, a large ICE travelling 25% of the average daily distance, or 7.2km/day, would produce lifetime emissions of 17.7 t of CO₂-eq/vehicle. Therefore, the combination of these two vehicle types and sizes travelling in alignment with this distance split, within this household scenario context, gives a total lifecycle emissions figure of 24 t of CO₂-eq.

With the small-sized EV being utilized most frequently, it is far more likely to exhibit a positive payback rate, overriding the payback point set by its initially high manufacture-based emissions faster than that of a larger vehicle, and thereby truly harnessing the net-zero operations-based emissions benefits of EVs. As for the larger, less frequently driven ICE vehicle, this contributes only

minimal emissions due to being driven only on occasion, and does not require a proportional driving distance frequency in order to offset early lifecycle emissions in the same way that a large-sized EV would.

Household vehicle split – Scenario 2:

The following scenario is based on the combination of a household owning two vehicles, one being a small ICE which is driven most frequently, and the other being a large EV, driven less frequently.

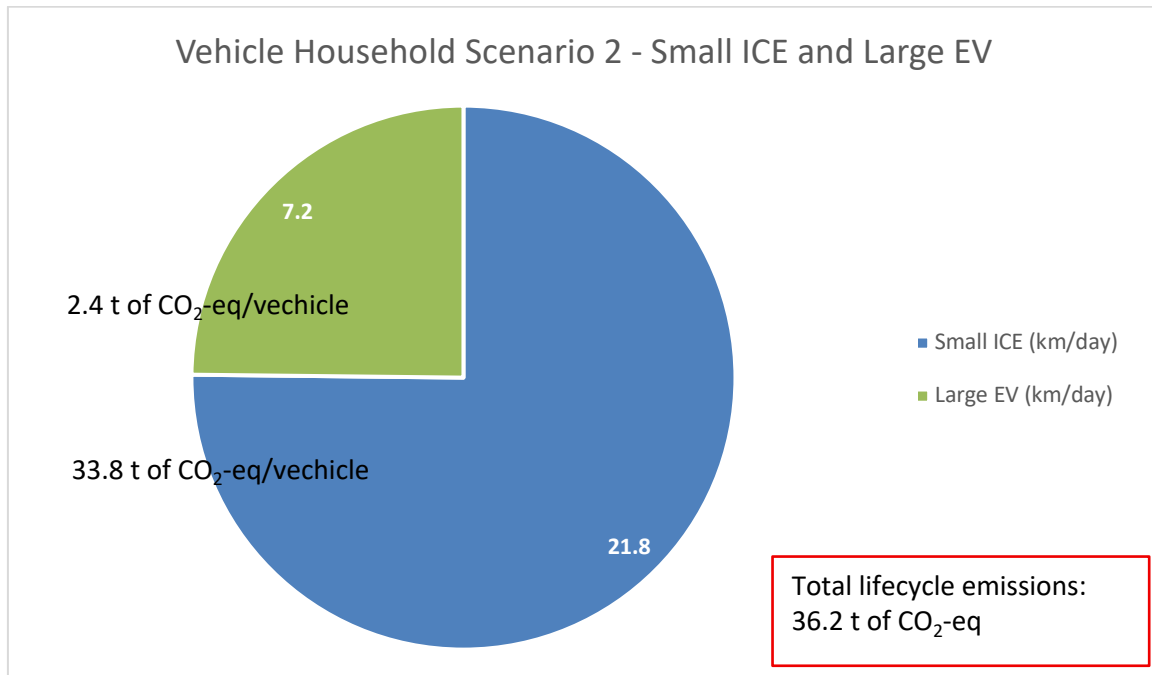


Figure 15 - Vehicle household split - Scenario 2

As evident within the figure above, a small ICE travelling 75% of the 29km/day total daily average, or 21.8km/day would produce lifetime emissions of 33.8 t of CO₂-eq/vehicle. In addition, a large EV travelling 25% of the average daily distance, or 7.2km/day, would produce lifetime emissions of 2.4 t of CO₂-eq/vehicle. Therefore, the combination of these two vehicle types and sizes travelling in alignment with this distance split, within this household scenario context, gives a total lifecycle emissions figure of 36.2. t of CO₂-eq. In comparison to other potential household vehicle scenarios, this proves not as efficient in terms of vehicle ownership emissions reduction.

With the small-sized ICE being utilized most frequently, it would contribute higher emissions than that of an alternative, more frequently driven EV due to its tank-to-wheel of fuel consumption and combustion emissions being produced increasingly the more the car is driven. As for the large-sized, less-driven EV, this is also not efficient for emissions reduction as it is more unlikely that the initial, high manufacturing emissions associated with the early stages of the vehicle's lifecycle will be offset

or overridden through proportionately smaller operation, meaning the net zero operations-based emissions of the EV are unlikely to be fully harnessed.

Household vehicle split – Scenario 3:

The following scenario is based on the combination of a household owning two vehicles, one being a small EV which is driven most frequently, and the other being a large EV, driven less frequently.

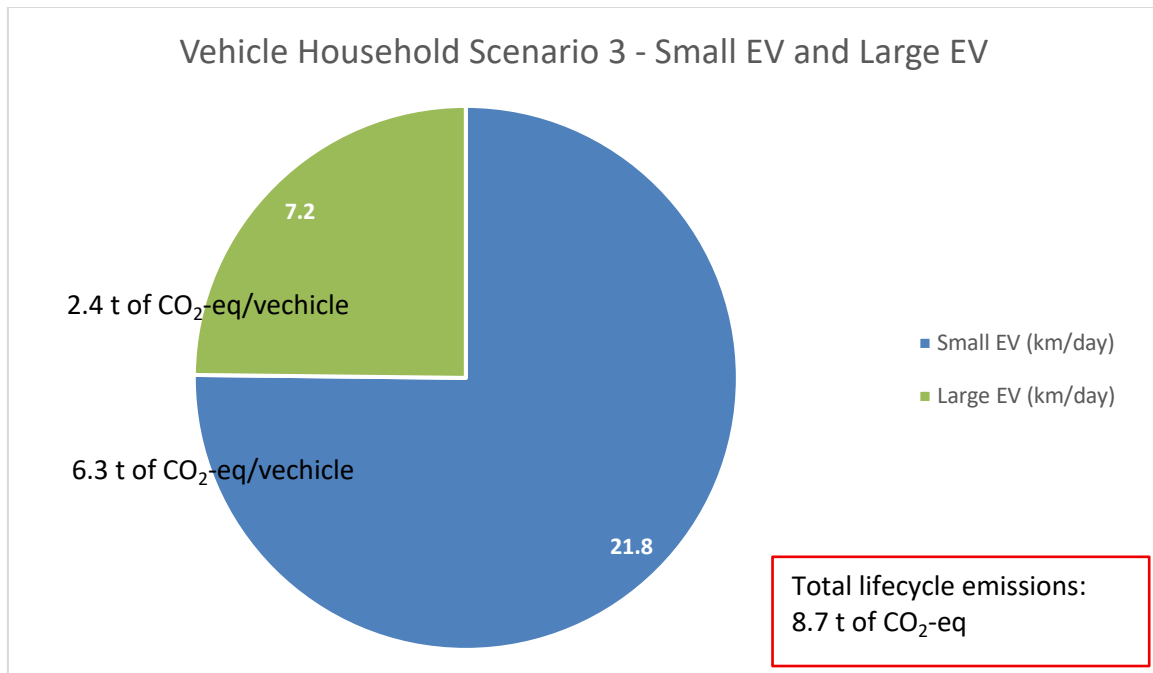


Figure 16 - Vehicle household split - Scenario 3

As evident within the figure above, a small EV travelling 75% of the 29km/day total daily average, or 21.8km/day would produce lifetime emissions of 6.3 t of CO₂-eq/vehicle. In addition, a large EV travelling 25% of the average daily distance, or 7.2km/day, would produce lifetime emissions of 2.4 t of CO₂-eq/vehicle. Therefore, the combination of these two vehicle types and sizes travelling in alignment with this distance split, within this household scenario context, gives a total lifecycle emissions figure of 8.7 t of CO₂-eq. In comparison to other potential household vehicle scenarios, this proves positive from a total lifecycle emissions basis, due to EVs, of all sizes, producing less overall lifecycle emissions than their ICE counterparts (see section 5.0).

With the small-sized EV being utilized most frequently, it is far more likely to exhibit a positive payback rate, overriding the payback point set by its initially high manufacture-based emissions faster than that of a larger vehicle, and thereby truly harnessing the net-zero operations-based emissions benefits of EVs. As for the large-sized, less-driven EV, whilst efficient in comparison to an ICE alternative from a total lifecycle emissions perspective, this is also not entirely efficient as it is

more unlikely that the initial, high manufacturing emissions associated with the early stages of the vehicle's lifecycle will be offset or overridden through proportionately smaller operation, meaning the net zero operations-based emissions of the EV are unlikely to be fully harnessed.

The above analysis of each possible scenario lead to the determination that the ideal household vehicle ownership combination, from a total lifecycle emissions perspective, is that of two EVs, with one small-size EV that travels majority of the required household distance alongside a large-size EV that is used less frequently. This is due to the fact that, being two EVs, the household contains two low-emission vehicles from a total lifecycle emissions perspective, despite the larger EV, less-used EV likely having an unsuccessful or inefficient payback rate, in comparison to that of other households with one or more higher-emissions ICE vehicles. Nevertheless, a household containing one smaller-sized EV that is utilized most frequently alongside a larger-sized ICE that is used less frequently is also a positive vehicle ownership combination for New Zealand households. Showing evidence towards only slightly more emissions on a total combined lifecycle basis, this vehicle combination remains an ideal option not only due to the small-sized EV being highly likely in reaching its payback point efficiently, but also because the large-sized ICE would contribute minimal emissions due to being driven less frequently and, not to mention, has no initial emissions payback rate to override through proportional operation.

Chapter 6 Discussion

6.0 Overview

This chapter provides a discussion based on the results found from this study (see chapter 5). Firstly, in relation to the earlier literature review (see chapter 3), a comparison of this research against that of pre-existing LCA studies is conducted, which is then followed by the provision and explanation of potential recommendations for New Zealand planning and policy. The analysis of this study against previous LCA publications, especially those within the New Zealand context, begins by discussing the similarities shared. Secondly, areas of contrast, or aspects of uniqueness of this dissertation are stated, serving as a discussion behind the rationale for this research and the contribution it can make to current policy and planning in New Zealand. Following this trajectory, the chapter concludes with a discussion surrounding the implications this research could have upon New Zealand policy and planning initiatives using the prior analysis surrounding gaps in the previous literature and what this new-found study seeks to provide in response.

6.1 Similarities to existing literature

In comparison to external New Zealand-based vehicle type LCA (see section 3.0.4), the results of this research show a number of similarities.

Both this dissertation and the pre-existing literature show a mutual determination of smaller-sized EVs as the most efficient vehicle for emissions reduction (Ellingsen et al., 2016, p. 4). This is due to EVs having larger emissions during the early stages of their life cycle, but exhibit net zero during their operation, whilst ICEs were determined to contribute emissions, and in large quantities compared to their EV counterparts, throughout all phases (Hawkins et al., 2013, p. 58-59). This calculation is based on not only a total life cycle emissions basis, but also from a consideration of the vehicle's ability to reach and override its earlier production-based emissions, with small-battery EVs being the best vehicle in each of these areas (Hawkins et al., 2013, p. 60-61). Likewise, this research and existing LCA show an understanding and incorporation of the impact early emissions offset, explaining that the life cycle emissions efficiency of an EV is heavily determined by how far it is driven over the course of its lifetime, or its ability to compensate for these emissions pertaining to its manufacture and supersede this offset quota (Nealer et al., 2015, p. 12).

In terms of battery replacement, various vehicle type LCA studies, both domestically as well as internationally, and this research included the impact of battery replacement within their investigations, also performing calculations that include this option for EVs. It was discovered that, whilst EV battery replacement does indeed increase EV lifecycle emissions, this addition to an already

operational vehicle is far more emissions-efficient than opting for an entirely new replacement vehicle unit and disposing the older model due to the vehicle distance travelled being doubled, and thereby indeed contributing less lifecycle emissions in comparison (Ellingsen et al., 2016, p. 4).

6.2 Areas of uniqueness

In contrast to the discussion above, this dissertation does exhibit methodological approaches and findings to previous New Zealand-based studies. These factors give this dissertation uniqueness, justifying its presence within the realm of vehicle type LCA and its potential to contribute to the field of nationwide emissions reduction vehicular planning and policy.

Whilst this research and that of pre-existing literature share the commonality of utilizing only government-provided, reputable sources (see section 4.0), existing vehicle type LCA work in New Zealand were conducted in previous years, meaning data deemed relevance at the time of publication is potentially not as accurate years later. Data subject to such change could include the likes of average daily distance travelled and average vehicle ages when scrapped. For instance, the EECA 'Life cycle assessment of electric vehicles' was published in 2015 (EECA, 2015, p. 1), meaning that this data, and the therefore the results found from these calculations, are over approximately one decade old at the time of this research investigation. In comparison to the data and results of this dissertation, conducted in the year of 2025 using only the most recent Ministry of Transport Fleet Statistics and Household Travel Survey data, there is concern for the accuracy of, and therefore applicability of, these findings.

Secondly, this dissertation shows a level of uniqueness through its two-step approach. Whilst an established LCA-standards-based tool, the IEA 'Life Cycle Assessment Calculator' is used as a basis for obtaining raw results pertaining to vehicle type LCA, the application of more specific New Zealand data was done so through the undertaking of additional calculations for increased accuracy of results. No other vehicle type LCA study, at least within the New Zealand context, shows evidence of a two-step methodology.

Finally, whilst other LCA studies discuss the influence of EV payback rates and varying driver behaviours, such as driving distance and vehicle lifespans (Hawkins et al., 2013, p. 60-61, Nealer et al., 2015, p. 12), this research utilizes these variables to conduct calculations incorporating such different scenarios for more extensive policy recommendations. By using the same static input value, existing LCAs lacked a level of policy implication that could extend beyond the nation-wide scale. By justifying and using different lifespan variables for battery replacement LCA calculations (see section 4.0.2) and split mode representative vehicle distance variables for two-car household analysis (see section 5.3.2), this dissertation provides results that represent a realistic nationwide fleet, optimizing

the opportunities for further results specialized results and therefore more diverse policy and planning recommendations. This uniqueness allows insight to surpass the static, nationwide per fleet or per vehicle-based framework, and delve more deeply into a per household scale for more real-world incentivization policy implications.

6.3 Policy/planning implications and recommendations

The provision of recommendations for New Zealand planning and policy development, in relation to vehicular type, ownership, and renewable energy transitions legislation, fulfils the requirements for answering the third research question stated within section 1.1.

- 3) What changes should be made to current and future New Zealand policy and planning in order to steer the privately-owned vehicular fleet to reduced LCA emissions?

As made clear within section 2.2, policy surrounding vehicle type incentivization for climate change mitigation within New Zealand has been inconsistent. From the early Car Scrappage Scheme in 2007 and 2009 (MoT, 2008, p. 3), to the 2021-2023 Clean Car Discount (MoT, 2025), followed by the fixed period exemption of road-user charges for EVs (NZTA, 2025a), and even the recently proposed rectified Clean Car Upgrade scrappage scheme in 2023 (New Zealand Parliament, 2022), very few of these objectives for vehicular climate change mitigation have remained fixed. With New Zealand undergoing an election-based change in national government very three years (DPMC, 2023), policies and programmes also appear to fluctuate depending upon who is in power. As a result, New Zealand is in need of a nationwide, legislative, solidified understanding as to what vehicle type is the best for emissions reduction through private vehicle ownership and operation, alongside consistent policy and planning mechanisms to reflect this direction.

6.3.1 Focused incentivization of smaller-sized EVs

From section 5.3.1 above, it is determined through the investigations of this research, in addition to being cross-referenced by existing literature surrounding vehicle type lifecycle impact assessment, that small-sized EVs are the ideal vehicle type in terms of emissions reduction. Policy and planning initiatives need to portray this in a way that anchored and can withstand frequent changes in government ideologies.

Incentivization through mechanisms such as price markdowns and subsidy provisions on electric vehicles is an ideal approach. With the previous Clean Car Discount (see section 2.2.1.2) resulting in increased private EV uptake by New Zealand drivers due to EVs becoming a more affordable and therefore desirable vehicle type choice (NZTA, 2024, p. 4), a similar scheme aimed at specifically incentivizing smaller-sized EVs is likely to escalate ownership numbers of this emissions-friendly

vehicle type whilst simultaneously solidifying the new recognition of smaller EVs as the best mode of private vehicle transportation and ownership for emissions reduction.

Having a lower payback rate, smaller-sized EVs, of any battery capacity, show to be better for emissions reduction, in comparison to larger EVs that have a higher override point for early lifecycle emissions offset, and therefore would provide the most benefits if incentivized, in comparison to their larger-sized EV counterparts. Incentivizing a larger-sized EV means that the vehicle has to be driven proportionately more than the distance equating to the initial manufacturing emissions produced in making the vehicle, meaning there is a higher likelihood that this offset of emissions point will not be reached or overridden by all drivers, depending on an individual's daily distance and travelling frequency, making larger-sized EV an inefficient option or increased uptake through motivated price markdown and subsidy support (see section 5.3.2). Smaller-sized EVs, on the other hand, have a lesser early lifecycle phase emissions point to compensate for, and could very well prove as a more successful incentivized vehicle type, rather than New Zealand drivers to using this financial aid to purchase larger EVs with a lesser guarantee that the net zero operations emissions benefit will actually be harnessed to the fullest.

6.3.2 Prioritization of incentivization and reward benefits for high-usage EVs

In relation to the above recommendation, an incentivization to motivate the uptake of smaller-sized EVs, as the vehicle type deemed best for emissions reduction, could revolve rewards being prioritized to those vehicle owners and operators who driver their EVs the most. As found within this research (see section 5.3.2), the more an EV is used, the more emissions reduction benefits it produces. New Zealand emissions reduction policy could utilize this given finding as the basis for incentivizing increased purchasing and operation of smaller-sized EVs by rewarding those who drive their vehicles frequently or for long distances accordingly. For instance, introducing a policy programme where EVs that are driven over certain set quotas are rewarded some form of incentive could prove to be successful for motivating not only the original purchase of the vehicle discussed in section 6.3.1, but also in a way that motivates its continued usage for an increased likelihood that the vehicle will actually override its early lifecycle emissions and therefore contribute its true emissions reduction potential of net zero operation. Schemes of this nature could be carried out on a timed basis where the quantity of kilometres travelled, as per the odometer reading, recorded at every annual WOF inspection is used to determine the level of usage of the vehicle, with the owner being rewarded if this distance meets or surpasses a set baseline qualifying for reward.

Prioritization of EV incentivization could also come in the form of the reward provision being allocated to categorized, guaranteed high-distance users. Examples of high vehicle users could include vehicles used for small-sized private and company-based taxi and Uber services, or rental

cars. Such vehicles, or the companies or individual drivers they belong to, could be eligible, through newly revised vehicle incentivization policy, for extensive benefits such as rebates, subsidies, or payouts per distance quota due to the increased guarantee of these vehicles being highly utilized, driven extensive kilometres, and thereby meeting and exceeding their emissions offset point for positive emissions reduction benefits. Incentivization such as this would encourage companies or individuals that tend to travel proportionately higher distances to partake in owning an EV, as the more emissions-friendly alternative, and therefore increase this desired behaviour in a way that ensures these emissions reduction benefits are successful.

6.3.3 Inclusion of EV battery replacement in incentive-based schemes

Another tactic for successful uptake of desired vehicle behaviours by New Zealand drivers lies in the potential of incentivized battery replacement. As detailed in section 5.3.1, the emissions-reduction benefits of an EV increase when the BEV battery is replaced. Policy programmes motivating vehicle owners to replace the battery in their electric vehicle, rather than opting to purchase an entirely new vehicle, would not only prove to be more beneficial for emissions reduction goals but could also be a more economic decision for the consumer. Literature shows that many consumers currently elect to replace the vehicle within an entirely new vehicle of similar cost, whether this be with another EV or even an ICE, rather than replacing the EV battery due to cost-related reasons (see section 5.3.1). Rebating battery replacements for such EVs not only could play a role in incentivizing drivers to purchase them in the first place but is also far more likely to motivate the retainment of these vehicles by their owners through making the emissions-preferred option more financially feasible for many prospective buyers. Including EV battery replacement schemes into the realm of desired vehicle type subsidization could potentially lead to a successful uptake in emissions-efficient smaller-sized EVs where people are increasingly acting sustainably, furthermore, by keeping them on the road in a way that this indefinitely more emissions-friendly in comparison.

6.4 Summary

The purpose of this chapter was to detail the similarities and differences between that of existing LCA literature and the methods and findings of this research, in addition to providing recommendations for future planning and policy mechanisms for New Zealand-based vehicular emissions reduction based on this analysis. Similarities evident between previous New Zealand vehicle type LCA work (see 3.0.4) and this dissertation involve the declaration of EVs, specifically smaller-sized EVs, as the best vehicle type option for emissions reduction. Additionally, both previous LCA work and this study included discussion surrounding the importance of EV payback rate within the vehicle's lifecycle and its ability to meet its true net zero emissions potential, as well as the determination that EV battery

replacement, whilst adding to the vehicle's emissions contributions, is more emissions-friendly than opting for a new replacement vehicle unit.

This dissertation shows many areas of uniqueness, namely in its utilization of the most recent, New Zealand-specific data for increased accuracy over other previous studies, a two-step method approach to calculating results for best accuracy, including the usage of an established LCA tool built upon standardized methods in addition to context-specific calculations, and the recognition and incorporation of varying vehicle lifetime distances and lifespans for specialized circumstances for the provision of different two-car household scenario results. Each of these aspects identified testify towards the importance of this dissertation, the uniqueness it contributes to the field, and the implications it provides to the realm of vehicle LCA in New Zealand planning and policy.

Taking the results of this study (see chapter 5) in combination with the areas of uniqueness listed (see section 6.2), recommendations for vehicular planning and policy revolve around the incentivization of smaller-sized EVs for the best emissions reduction results. Focusing incentivization for smaller-sized EVs, rather than providing the same level of incentivization to larger-sized EVs, which are statistically less likely to meet and exceed their original production-based emissions for maximized emissions reduction benefits (see section 5.3.2), was the leading suggestion. Accompanying this was the recommendation for prioritized incentivization for EVs, or, in other words, providing additional incentive rewards for drivers showing high utilization of their EV and for special purpose vehicles that undertake large travel distances. In addition, the inclusion of EV battery replacement within incentivization policies, as a way of providing a more appealing or feasible alternative to opting for an entirely new vehicle unit, would also positively impact vehicular emissions reduction within New Zealand.

Chapter 7 Conclusion

In conclusion, this research conducted a lifecycle analysis and comparison of the different vehicle technologies, being ICE and EV, within the context of New Zealand. Then, using the results generated, recommendations surrounding the implications and opportunities this could have upon New Zealand planning and policy, in order to meet align with emissions-reduction nationwide, was also discussed. This was achieved by formulating and answering specific research questions, done so through the undertaking of domestic and international vehicular policy case studies, a review of the current literature surrounding vehicle LCA, assessment of LCA tools, and finally the generation of results, using the selected tool, pertaining to lifecycle emissions for both vehicle types, all sizes, and battery capacity options.

Background research provided the definition of LCA as “an analytical tool for the systematic and quantitative evaluation of the environmental impacts of a product or service system through all stages of its life” (LCANZ, 2019) with its relation to vehicle type impact analysis being through its all-encompassing, holistic, cradle-to-cradle approach allowing for extensive comparison. Case study evaluation of New Zealand-based vehicular transition policy demonstrated a leading objective for this research; legislation that recognizes the most emissions-efficient vehicle type and consistently incentivizes this, surviving unrevoked despite the frequent changes in government party agendas. In support of this, international examples of emissions-reduction vehicle policy and planning exemplified steady goals and mechanisms for successful sustainable vehicle uptake within their respective countries, providing inspiration for what the results of this research could assist in achieving in New Zealand.

Following this was a literature review consisting majorly of academic journal articles that have also conducted similar vehicle LCA. Examination into these existing publications showed that greenhouse gas emissions is most definitely considered a leading determining factor for vehicle type emissions-reduction suitability and therefore a reoccurring focus of many LCAs worldwide. Driving behaviours, such as the frequency of and reasons for light vehicle trips were also reiterated themes within the literature, proving to be pivotal to vehicle LCA, in addition to many papers extending the LCA beyond the boundaries of the disposal phase in incorporate recycling and long-lasting vehicles into the lifecycle, something which, whilst contributing emissions to the overall vehicle lifecycle, also extends the lifespan, therefore showing increased sustainability. Various vehicle type LCAs endemic to New Zealand were also summarized, yet showed gaps within the research involving utilization of the most recent data and policy approaches catered to different driver behaviours and vehicle ownership, providing reason for this dissertation study. As a secondary part of the literature review, an

assessment of LCA tools led to the selection of the IEA Lifecycle Assessment Calculator as the chosen application for conducting this research based on the input value options available and the relevance of the output values it provides.

Assumptions and limitations surrounding this research involve the inevitable, future-focused fluctuations of the data required, making this investigation relevant to the current time period of this research and highlighting the need for continued reassessment with the release of annual-basis governmental institutional data. Looking at the IEA Lifecycle Assessment Calculator tool specifically, omission of a New Zealand region option meant additional steps were added to the methodology to ensure place-based accuracy, and the exclusion of adequate input options for SUV and pickup-sized EVs meant that the comparison standard for both EVs and ICEs was limited to simple small, medium, and large vehicle masses.

Results generated from this research showed EVs, the more successful option for emissions-reduction due to the smaller total lifecycle emissions all EV sizes produced in comparison to ICEs. However, the large early lifecycle emissions of EVs were pinpointed for discussion, and led to the determination that EVs must be driven frequently, on a basis that is proportionate to the initial emissions associated with their manufacturing, in order to offset this and thereby truly harness the lower overall lifecycle emissions and net zero operation characteristic of EVs. This meant that the ideal, emissions-reduction vehicle would be a smaller-sized EV, and the ideal vehicle combination for the generic New Zealand two-car household proved to be a small EV coupled with a larger EV.

Finally, taking into account these results, discussion found similarities and differences between the findings of this research and that of existing literature, specifically LCAs of similar nature already conducted within the New Zealand context. Similarities include the shared conclusion that smaller-sized EVs are the vehicles with the lowest lifecycle emissions. Furthermore, whilst best for emissions reduction from a total lifecycle perspective, do pertain to large-scale emissions within the early production phase, and therefore must be driven to compensate for such impacts. This research shows its uniqueness through its usage of the most current data sources, two-step method approach for increased accuracy of calculations, and its ability to use diverse vehicle lifespan and driver distance inputs to not only provide an additional analysis concerning ideal household vehicle combinations, but to also open discussion surrounding policy recommendations that represent diverse drivers within New Zealand, not just simply one static overall fleet. All of these were items that was not seen to the same extent in previous New Zealand-based studies, and served as a leading objective for this investigation.

7.0 Future work

Future work to continue the discussions and findings of this research revolve around the need for continued vehicle type LCA due to the foreseeable changes in data provisions with each passing year. Whilst this research used only the most recent and reputable data available, limitation lies in the fact that crucial governmental information such as driver distances travelled, emissions factors, and vehicle scrappage statistics, all provided by Waka Kotahi The New Zealand Transport Agency and the Ministry for Transport, are inevitably susceptible to change with each calendar year (see section 4.2.1). Continuing to perform LCA of the emissions of ICEs and EVs specific to the New Zealand context is critical to ensure the information provided by this research is kept current and in alignment with any substantial changes in the data trends that could impact these results.

It is also important to recognize the evolving trends in automotive manufacturing, where technological methods, materials used, and production practices are open to change throughout this transition to more renewable options. As EV technology progresses, and manufacturing materials are expected to evolve, the greenhouse gas emissions contributions of these different innovations are also very likely to be different (Liu et al., 2020, p. 394-395). Reason for continued vehicle type LCA may not only be limited to the need for the most recent annual data, but also in order to keep in alignment with developments in the automotive industry and new emerging technologies as vehicle types progress, become more widespread, and the concern for global emissions reduction and climate mitigation intensifies.

Specifically looking at the IEA Lifecycle Assessment Calculator, limitations surrounding the tool's lack of input options for SUV or pickup-sized EVs would benefit from some refiguration. Emerging multipurpose vehicle models, prime examples being the BYD Shark (Manins, 2024) indicate a need for an update in the tool that reflects the expansion beyond the standard small, medium, and large vehicles sizes appearing within the industry. Enhancing the IEA Lifecycle Assessment Calculator in this way would allow for more in-depth and accurate analysis that recognizes all vehicle types and sizes that are expected to see increasing rates of production, purchase, and operation in the modern market. Similarly, the tool does not include recycling or end-of-life emissions LCA results generation, something which could also be added to for further, all-encompassing LCA examination in the future.

Whilst this research has focused on the impacts of production, well-to-tank, tank-to-wheel, and battery replacement emissions in relation to vehicle type, an LCA can be expanded to include various holistic contributing factors, including environmental, social, and cultural aspects, for a more all-encompassing approach. These can be described as areas for future investigation based on the findings of this research and the insights provided for New Zealand planning and policy. With the

findings of this research resulting in small-sized electric vehicles being the most emissions-efficient, an in-depth understanding and consideration for the implications on vehicle type LCA that each of these identified aspects are likely to have is therefore necessary to understand the implications these additional areas could have on LCA, and in turn the results pertaining to these vehicles. All aspects listed are expected to, in some manner, effect the lifecycle, product lifespan, manufacturing feasibility, or even the consumer uptake of these vehicles, hence there is a vitality that these are considered when continuing regular, in-depth vehicle type LCA in the coming future.

Recycling practices, whether this be repurposing of vehicular body materials or end-of-life disposal processes also pertains to emissions contributions, which are to be included as part of the overall lifecycle of the vehicle. More interestingly, the potential for emissions variation or impact of the lifespan length of EVs due to emerging technological utility opportunities, namely vehicle-to-grid (V2G) systems for reformed electricity generation and storage, await further examination due to the nascent nature of these future-focused, emerging developments.

Moreover, a LCA result that points to a certain vehicle as the preferred type is limited in what it can achieve when not paired with successful incentivization and provision. As discussed in section 6.1, planning and policy implications derived from the results of this research point to the need for consistent policy that actively portrays the result of smaller-sized EVs as the most ideal vehicle type for light vehicle transportation-based emissions reduction. Incentivization of these vehicles for increased uptake and usage brings to light the possible concern of resource scarcity. Future work needs to consider the sustainability of the material extract phase, namely how these levels of lithium-iron and cobalt used to manufacture EV batteries will be able to meet this potentially increasing demand. More interestingly, the presence of cultural inertia surrounding vehicle type ownership, based on social perspectives of consumers, is something which New Zealand specifically may find as a unique area for future work. Literature shows that the desire to own a certain vehicle type or size in New Zealand is considered more important to drivers than that of emissions reduction-incentivized vehicles, purely for the reason of social status or conforming to a certain desired lifestyle. This could cause a barrier to the incentivization of smaller-sized EVs, but future work surrounding ideal household vehicle combinations within this research, promoting a frequently used smaller-sized EV accompanied by a less-operated ICE as an option that remains emissions-friendly, could provide avenues for addressing this issue in a way that balances emissions reduction and lifecycle choice for the New Zealand driver.

References

- Argonne National Laboratory. (n.d.). *AFLEET Payback on-road calculator*. AFLEET Online. <https://afleet.esia.anl.gov/afleet/payback-onroad-calculator>
- Argue, C. (2025, January 20). *EV battery health insights: Data from 10,000 cars*. Geotab. <https://www.geotab.com/blog/ev-battery-health/>
- Bieker, G. (2021). *A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars*. The International Council on Clean Transportation (ICCT). https://theicct.org/sites/default/files/publications/Global-LCA-passenger-cars-jul2021_0.pdf
- Broadbent, G. H., Wiedmann, T. O., & Metternich, G. I. (2021). Electric vehicle uptake: Understanding the print media's role in changing attitudes and perceptions. *World Electric Vehicle Journal*, 12(4), 174. <https://doi.org/10.3390/wevj12040174>
- Concept Consulting Group Ltd. (2016). *Electric cars, solar panels and batteries – how will they affect New Zealand's greenhouse gas emissions?* https://www.concept.co.nz/uploads/1/2/8/3/128396759/new_technologies_emissions_report_final.pdf
- Department of the Prime Minister and Cabinet (DPMC). (2023, April 19). *The electoral cycle*. <https://www.dPMC.govt.nz/our-business-units/cabinet-office/supporting-work-cabinet/cabinet-manual/6-elections-transitions-and-government-formation/electoral-cycle>

- Electric Vehicle Council. (2023a, November 29). *Lifecycle emissions calculator*. <https://electricvehiclecouncil.com.au/lifecycle-emissions-calculator/>
- Electric Vehicle Council. (2023b). *A comparison of lifecycle emissions between BEVs and ICE vehicles in Australia*. <https://electricvehiclecouncil.com.au/wp-content/uploads/2023/11/20231129-EVC-Lifecycle-Emissions-Calculator-Explainer.pdf>
- Ellingsen, L. A., Singh, B., & Hammer Strømman, A. (2016). The size and range effect: lifecycle greenhouse gas emissions of electric vehicles. *Environmental Research Letters*, 11(5), 1-9. DOI:10.1088/1748-9326/11/5/054010
- Energy Efficiency and Conservation Authority (EECA). (2015). *Life cycle assessment of electric vehicles*. <https://www.eeca.govt.nz/assets/EECA-Resources/Research-papers-guides/ev-lca-final-report-nov-2015.pdf>
- Finkbeiner, M., Inaba, A., Tan, R., Christiansen, K., & Klüppel, H. (2006). The new international standards for life cycle assessment: ISO 14040 and ISO 14044. *The International Journal of Life Cycle Assessment*, 11(2), 80-85. <https://doi.org/10.1065/lca2006.02.002>
- Hall, D., & Lutsey, N. (2018). *Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions*. The International Council on Clean Transportation (ICCT). https://theicct.org/wp-content/uploads/2021/06/EV-life-cycle-GHG_ICCT-Briefing_09022018_vF.pdf
- Hasan, M. A., Frame, D. J., Chapman, R., & Archie, K. M. (2021). Costs and emissions: Comparing electric and petrol-powered cars in New Zealand. *Transportation Research Part D: Transport and Environment*, 90, 1-13. DOI: 10.1016/j.trd.2020.102671

Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Hammer Strømman, A. (2013). Comparative environmental life cycle assessment of conventional and electric vehicles. *Journal of Industrial Ecology*, 17(1), 53-

64. DOI: [10.1111/j.1530-9290.2012.00532.x](https://doi.org/10.1111/j.1530-9290.2012.00532.x)

Helmers, E., Dietz, J., & Weiss, M. (2020). Sensitivity analysis in the life-cycle assessment of electric vs. combustion engine cars under approximate real-world conditions. *Journal of Sustainability*, 12(3), 1-

31. DOI: [10.3390/su12031241](https://doi.org/10.3390/su12031241)

International Energy Association (IEA). (2024a, June 5). *EV life cycle assessment*

calculator. <https://www.iea.org/data-and-statistics/data-tools/ev-life-cycle-assessment-calculator>

International Energy Association (IEA). (2024b). *Method statement - Life cycle assessment*

(LCA). <https://www.iea.org/data-and-statistics/data-tools/ev-life-cycle-assessment-calculator#methodology>

Jayakumar, A., Chalmers, A., & Lie, T. T. (2017). Review of prospects for adoption of fuel cell electric vehicles in New Zealand. *IET Electrical Systems in Transportation*, 7(4), 259-266. <https://doi.org/10.1049/iet-est.2016.0078>

Khaleel, M., Nassar, Y., El-Khozondar, H., Elmmif, M., Rajab, Z., Yaghoubi, E., & Yaghoubi, E. (2024). Electric vehicles in China, Europe, and the United States: Current trend and market comparison. *International Journal of Electrical Engineering and Sustainability (IJEES)*, 2(1), 1-

20. <https://ijeess.org/index.php/ijeess/article/view/70/36>

Life Cycle Association of New Zealand (LCANZ). (2019, June 19). *Introduction to LCA*. <https://lcanz.org.nz/lca-guidance/lca-intro/>

Liu, G., Li, K., Wang, Y., Luo, H., & Luo, H. (2020). Recent advances and trend of HEV/EV-oriented power semiconductors – an overview. *IET Power Electronics*, 13(3), 394-404. <https://doi.org/10.1049/iet-pel.2019.0401>

Manins, D. (2024, November 7). *BYD shark 6 review: The hybrid Ute that changes everything*. Driveline Fleet. <https://www.driveline.co.nz/byd-shark-6-review-the-hybrid-ute-that-changes-everything/>

Ministry for the Environment. (2024). *Aotearoa New Zealand's 2035 international climate change target*. <https://environment.govt.nz/publications/opportunity-for-public-feedback/>

Ministry for the Environment (MfE). (2025, May 27). *New emissions factors released*. <https://environment.govt.nz/news/new-emissions-factors-released/>

Ministry of Transport (MoT). (2008). *Report on the Trial Vehicle Scrappage in Auckland May – June 2007*. <https://www.transport.govt.nz/assets/Uploads/Report/Vehicle-Scrap-Report30July-2.pdf>

Ministry of Transport (MoT). (2009). *A vehicle scrappage trial for Christchurch and Wellington: May 2009*. <https://www.transport.govt.nz/assets/Uploads/Report/Scrappage-Report-FINAL.pdf>

Ministry of Transport (MoT). (2022). *Land Transport (Clean Vehicles) Amendment Bill (No 2) - Approval for Introduction Proposal*. <https://www.transport.govt.nz/assets/Uploads/Land-Transport-Clean-Vehicles-Amendment-Bill-No-2-Approval-for-Introduction-Cabinet-Paper.pdf>

Ministry of Transport (MoT). (2023). *Regulatory Impact Statement: Discontinuing the Clean Car Discount*. <https://www.transport.govt.nz/assets/Uploads/regulatory-impact-statement-terminating-the-CCD-FINAL-30-November-2023-REDACTED.pdf>

- Ministry of Transport (MoT). (2024a). *Annual Fleet Statistics*. Fleet Statistics. <https://www.transport.govt.nz/statistics-and-insights/fleet-statistics/sheet/annual-fleet-statistics>
- Ministry of Transport (MoT). (n.d.). *Our vehicle scrappage trials*. <https://www.transport.govt.nz/about-us/what-we-do/queries/vehicle-scrappage-trials>
- Ministry of Transport (MoT). (2024b). *Household Travel Survey*. <https://www.transport.govt.nz/statistics-and-insights/household-travel>
- Ministry of Transport (MoT). (2025). *Clean Cars*. <https://www.transport.govt.nz/area-of-interest/environment-and-climate-change/clean-cars>
- Nealer, R., Reichmuth, D., & Anair, D. (2015). *Cleaner cars from cradle to grave*. Union of Concerned Scientists. <https://www.ucs.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf>
- Neidhardt, M., Mas-Peiro, J., Schneck, A., Pou, J. O., Gonzalez-Olmos, R., Kwade, A., & Schmuelling, B. (2022). Automotive electrification challenges shown by real-world driving data and lifecycle assessment. *SSRN Electronic Journal*, 14(23), 15972. <https://doi.org/10.3390/su142315972>
- New Zealand Government. (2024, March). *Draft Government policy Statement on Land Transport 2024-34*. Ministry of Transport. <https://www.transport.govt.nz/assets/Uploads/GPS-on-land-transport-2024-Consultation-4-March-2023-.pdf>
- New Zealand Parliament. (2022, November 22). *Tuesday, 22 November 2022 (continued on Thursday, 24 November 2022) - Volume 764*. https://www3.parliament.nz/mi/pb/hansard-debates/rhr/combined/HansD_20221122_20221124

New Zealand Parliament. (2023, April 4). *Tuesday, 4 April 2023 - Volume*

767. https://www3.parliament.nz/en/pb/hansard-debates/rhr/combined/HansD_20230404_20230404

New Zealand Transport Agency Waka Kotahi (NZTA). (2024). *Clean Car Discount Monthly Report - January*

2024. <https://www.nzta.govt.nz/assets/About-us/docs/oia2-2024/clean-car-discount-monthly-report-january-2024.pdf>

New Zealand Transport Agency Waka Kotahi (NZTA). (2025). *RUC for electric*

vehicles. <https://www.nzta.govt.nz/vehicles/road-user-charges/ruc-for-electric-vehicles>

New Zealand Transport Agency Waka Kotahi (NZTA). (2025a). *Electric*

vehicles. <https://nzta.govt.nz/vehicles/vehicle-types/electric-vehicles>

Norsk elbilforening. (2025). *Norwegian EV Policy*. <https://elbil.no/english/norwegian-ev-policy/>

Pei, Y. (2025, May 20). *China's expanded incentives for scrapping and replacing transportation equipment in*

2025. International Council on Clean Transportation (ICCT). <https://theicct.org/publication/chinas-expanded-incentives-for-scrapping-and-replacing-transportation-equipment-in-2025-may25/>

Reguyal, F., Wang, K., & Sarmah, A. K. (2023). Electrification of New Zealand transport: Environmental impacts and role of renewable energy. *Science of the Total Environment*, 894, 1-

10. <https://doi.org/10.1016/j.scitotenv.2023.164936>

Ritchie, H. (2024, February 26). *Tracking global data on electric vehicles*. Our World in

Data. <https://ourworldindata.org/electric-car-sales>

Romare, M., & Dahllöf, L. (2017). *The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries* (C 243). IVL Swedish Environmental Research

Institute. <https://www.energimyndigheten.se/globalassets/forskning--innovation/transporter/c243-the-life-cycle-energy-consumption-and-co2-emissions-from-lithium-ion-batteries-.pdf>

Stats NZ. (2021, August 25). *Vehicles and petroleum contribute to large import*

month. <https://www.stats.govt.nz/news/vehicles-and-petroleum-contribute-to-large-import-month/#:~:text=In%20July%202021%20the%20top,0%20200M%20400M%20Stats%20NZ>

Svoboda, M., Fanta, M., & Mošovský, J. (2023). *Effectiveness of car scrappage schemes: Comparative analysis of European countries*. Institute of Economic Studies, Faculty of Social Sciences Charles

University. https://ies.fsv.cuni.cz/sites/default/files/uploads/files/wp_2023_28_svoboda%2C%20fanta%2C%20mosovsky.pdf

Appendix A

Raw LCA findings – Results prior to adjustment for NZ context

The following tables pertain to the two-step method approach of this research. As described in section 4.0.3, results were generated by inserting data input values the selected LCA tool (the IEA Life Cycle Assessment Calculator), giving raw results before performing additional manual calculations for adjustment of accuracy to the New Zealand context. These raw results, prior to their further refinement, are displayed for each vehicle type below.

Table 5 - Raw LCA results generated for ICEs

Vehicle Characteristics	Car production phase emissions (tCO ₂ -eq/vehicle)	Energy production (well-to-tank) phase emissions (tCO ₂ -eq/vehicle)	Fuel consumption (tank-to-wheel) phase emissions (tCO ₂ -eq/vehicle)	Total lifetime emissions (t of CO ₂ -eq)
Small (1030 kg)	2.7	11.1	29.8	43.6
Medium (1420 kg)	3.7	12.4	33.3	49.5
Large (1870 kg)	4.9	14.3	38.4	57.6
Pickup (1870 kg)	4.9	19.9	53.3	78.1
SUV (1740 kg)	4.6	19.1	51.1	74.8

Table 6 - Raw LCA results generated for EVs

Vehicle Characteristics	Car production phase emissions (tCO₂-eq/vehicle)	Energy production (well-to-tank) phase emissions (tCO₂-eq/vehicle)	Battery production phase emissions (tCO₂-eq/vehicle)	Total lifetime emissions (t of CO₂-eq)
Small (840kg), 100km range	2.1	13.5	1.3	17
Small (840kg), 150km range	2.1	13.5	2	17.7
Small (840kg), 200km range	2.1	13.5	2.7	18.3
Medium (1250kg), 150km range	3.3	13.5	2.3	19.1
Medium (1250kg), 200km range	3.3	13.5	3	19.8
Medium (1250kg), 250km range	3.3	13.5	3.8	20.6
Medium (1250kg), 300km range	3.3	13.5	4.5	21.3
Large (1380kg), 300km range	3.6	13.5	5	22.1
Large (1380kg), 350km range	3.6	13.5	5.8	22.9
Large (1380kg), 400km range	3.6	13.5	6.7	23.8
Large (1380kg), 450km range	3.6	13.5	7.5	24.6
Large (1380kg), 500km range	3.6	13.5	8.4	25.4

Table 7 - Raw LCA results generated for EVs with battery replacement

Vehicle Characteristics	Car production phase emissions (tCO₂-eq/vehicle)	Energy production (well-to-tank) phase emissions (tCO₂-eq/vehicle)	Battery production phase emissions (tCO₂-eq/vehicle)	Battery Replacement emissions (tCO₂-eq/vehicle)	Total lifetime emissions (t of CO₂-eq)
Small (840kg), 100km range	2.1	27	1.3	0.9	31.3
Small (840kg), 150km range	2.1	27	2	1.3	32.4
Small (840kg), 200km range	2.1	27	2.7	1.7	33.5
Medium (1250kg), 150km range	3.3	27	2.3	1.4	34
Medium (1250kg), 200km range	3.3	27	3	1.9	35.2
Medium (1250kg), 250km range	3.3	27	3.8	2.4	36.5
Medium (1250kg), 300km range	3.3	27	4.5	2.9	37.7
Large (1380kg), 300km range	3.6	27	5	3.2	38.8
Large (1380kg), 350km range	3.6	27	5.8	3.8	40.2
Large (1380kg), 400km range	3.6	27	6.7	4.3	41.6
Large (1380kg), 450km range	3.6	27	7.5	4.8	42.9
Large (1380kg), 500km range	3.6	27	8.4	5.4	44.4

Appendix B

IEA Life Cycle Assessment Calculator - EV battery lifespan assumptions

The following includes a link to the source cited within the methodology of the IEA Life Cycle Assessment Calculator pertaining to the information which they base their workings surrounding EV battery lifespan and replacement. This information, due to being part of the selected tool's methodology, was used to determine and justify the lifespan values used for EVs with battery replacement within this research (see section 4.0.2).

Argue, C. (2025, January 20). *EV battery health insights: Data from 10,000 cars*.

Geotab. <https://www.geotab.com/blog/ev-battery-health/>



Key Insights

- **EV battery lifespan:** Most EV batteries last 15-20 years, with an average degradation rate of about 1.8% per year under moderate conditions.

Figure 17 - Key insight for EV battery lifespan used by IEA Life Cycle Assessment Calculator