Auckland LIGHT RAIL
Bringing us closer

Whole of Life Carbon Assessment

17 September 2021

Revision | Final

Issue and revision record

Whole of Life Carbon Assessment						
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Abbreviations

Acronym	Description
ALR	Auckland Light Rail
AT	Auckland Transport
IBC	Indicative Business Case
MoE	Ministry of Environment
MoT	Ministry of Transport
MSM	Macro Strategic Model
NLTP	National Land Transport Plan
VEPM	Vehicle Emission Prediction Model
VKT	Vehicle Kilometre Travelled
WoL	Whole of Life

1 Introduction

This report outlines the whole of life carbon assessment for Auckland Light Rail (ALR). It captures the second assessment conducted in September 2021 to inform the project's Indicative Business Case option refinement process.

It provides details of the assessment method applied in order to estimate the quantum of carbon emissions impact.

The seven sources of emission contribution and emission savings include:

1. Source 1 - Emissions from ALR asset construction activities.
2. Source 2 - Emissions from ALR asset operational activities.
3. Source 3 - Emissions from transport users across Auckland due to the impact of ALR.
4. Source 4 - Emission savings from reduced road construction and car parking spaces across Auckland due to the impact of ALR.
5. Source 5 - Emissions savings due to lower energy requirements of denser housing typologies along ALR corridor.
6. Source 6 - Emission savings due to urban design elements.
7. Source 7 - Embedded EV emissions

The assessment determines the potential carbon emissions contribution and savings of three IBC options:

- Option 1a – Dominion Road Light Rail
- Option 2b – Sandringham Light Metro
- Option 3 - Sandringham Light Metro/Light Rail Hybrid
- Do-minimum option - City population growth excluding ALR and committed projects.

This assessment was conducted based on the MSM outputs dated 31 August 2021.

Assessment approach

- **Whole of Life Carbon Assessment for IBC MCA** - To conduct the IBC MCA the emission contribution and savings sources 1 to 5 were used to develop WoL Profile 3. The profile was used to choose the preferred option. The WoL only took into account emission reduction interventions that had different design elements across the options. It excluded the interventions that were consistently applied across all the options.
- **Overall Project Carbon Performance** - To account for the emission reduction interventions that were applied consistently across the options. A carbon performance assessment was conducted which looked at the level of application of tailpipe emission reduction activities. This took into account the emission reduction potential of these interventions, as well as source 6 (emission savings due to urban design elements) and source 7 (embedded EV emissions) to provide an indicate emission reduction potential of the project overall.

1.1 Project description

The ALR Project is a key transport priority for Auckland. The Ministry of Transport, Waka Kotahi NZ Transport Agency, Auckland Council, Auckland Transport, Kāinga Ora, and Mana Whenua are working collaboratively on the Auckland Light Rail project to investigate how light rail or light metro could best support current and future city growth. The ambition is to deliver light rail or light metro between the Auckland city centre and Māngere[1] as shown in Figure 1-1.

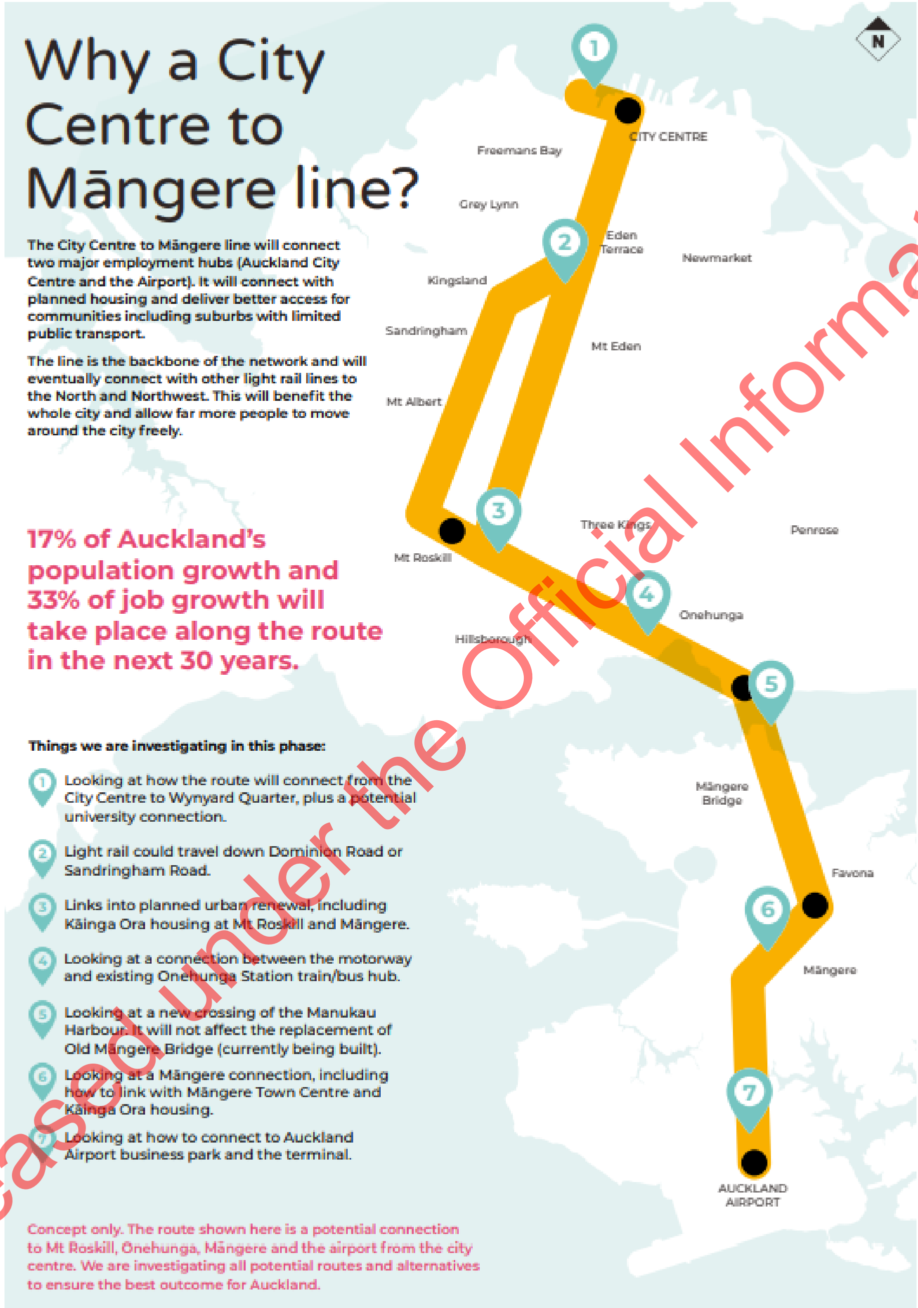

Figure 1-1: Auckland Light Rail IBC. Source: https://www.lightrail.co.nz/light-rail/resources/

[1] https://www.lightrail.co.nz/?gclid=CjwKCAjwyIKJBhBPEiwAu7zll-gNJBUzZ82JeAJLJqzW8xewV816w7saZQ9R7N6SD4zuGhjTji2n8BoCRzwQAvD_BwE&gclsrc=aw.ds

1.2 What this report informs

The results of this Whole of Life (WoL) carbon emissions assessment informs the strategic case, economic case, options development and urban workstream of the ALR project.

Figure 1-2 below outlines where the carbon narrative is embedded within the IBC by illustrating the main carbon analyses undertaken, and the relevant chapters in this report for further detail.

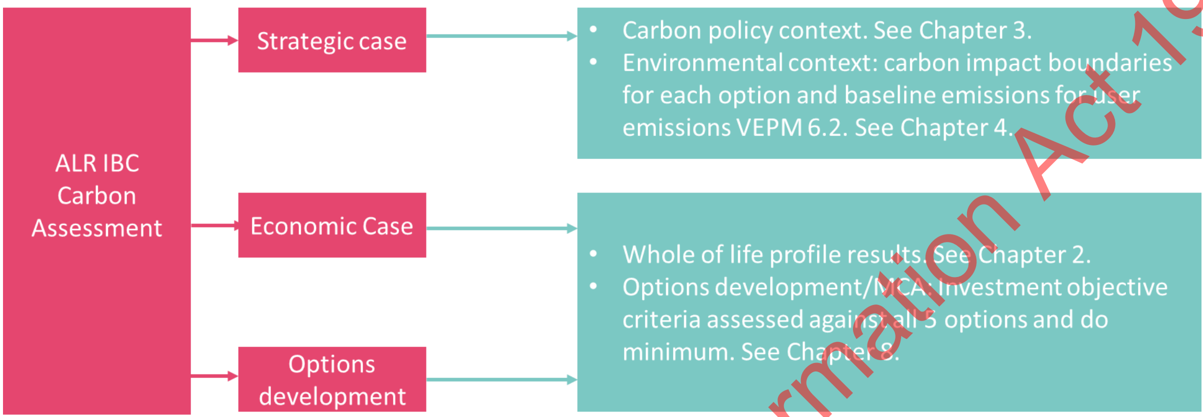

Figure 1-2: Carbon assessment informing the ALR IBC.

The results of this WoL carbon emissions assessment will also inform the Ministry of Environment's (MoE) Climate implications of policy assessment (CIPA)[2] advice, and considerations regarding potential Infrastructure Sustainability Council rating certification (ISC)[3] of the project.

2 The ALR carbon narrative

There are three carbon emissions analyses associated with ALR project, focussing on carbon emissions from construction activities, operational activities, and road user vehicles across the Auckland transport network. Road transport is a significant contributor to Auckland's carbon emissions profile. Introducing enhanced access to efficient public transport to and from the city centre will provide the opportunity to reduce Auckland's transport carbon emissions.

Auckland Council's 'Te Tāruke-ā-Tāwhiri Auckland's Climate Plan identifies its goal to increase public transport mode share[4]. ALR aims to provide a public transport rapid transit solution via either light metro or light rail. ALR is expected to help Auckland transition to a larger share of travel by public transport, particularly from private vehicles (mode shift). Attracting drivers away from independent car travel toward utilising ALR will contribute to carbon emission reductions over the lifespan of the ALR scheme. ALR rapid transit will carry

[2] https://environment.govt.nz/guides/climate-implications-of-policy-assessment-guidance-on-cabinet-requirement-for-central-government-agencies/
[3] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/environment-and-social-responsibility/sustainability-rating-schemes/
[4] https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/topic-based-plans-strategies/environmental-plans-strategies/aucklands-climate-plan/Documents/auckland-climate-plan.pdf

more people per trip than cars and buses and will therefore result in lower carbon emissions per passenger per kilometre.

2.1 Key findings

Will ALR contribute to reducing Auckland's carbon emissions?

- ALR is expected to contribute to reducing road user emissions in Auckland. The light rail options have a better carbon emissions profile (emission reductions are achieved earlier over time) when compared to the do minimum.

How are carbon emissions estimated?

- Carbon emission sources included construction and operational activities
- Carbon emission savings came from transport user emissions, avoided road construction and lower energy requirements in denser housing typologies along the corridor.
- Emissions are estimated for construction and operation stages of ALR as well as the impact on the wider network from road user emissions from available data sources and benchmarked projects.
- The largest WoL carbon impacts are the transport user emissions.
- The factors assessed with the most material impacts on carbon reduction include infrastructure and household energy consumption from Profile 3.

Impacts on the Auckland transport network

- ALR rapid transit carries more people per trip than cars and buses and therefore results in lower carbon emissions per passenger per kilometre.
- ALR options encourage mode shift away from passenger vehicle to PT.
- Interventions designed into ALR support a predominant "Shift" and "Improve" strategy.

Assessment Outcomes

- The outcome of the Whole of Life carbon assessment used to compare and choose a preferred option showed Option 3 as the preferred option.
- The outcome of the Overall Project carbon performance showed that there are some emission reduction interventions out of control of the project (i.e. controlled by other government bodies) that have not been adopted that would result in emission savings due to the ALR project. The full list of interventions have been illustrated in the Intervention Suite in Chapter 7.3. Majority of the emission reduction interventions that can be controlled by the project have been adopted. As detailed design information is produced the level of emission reduction potential will be able to be assessed.
- As more detailed and accurate information about the design becomes available more accurate analysis should be undertaken at the DBC stage to determine a clearer projection of the whole of life carbon profile of ALR and whole project carbon performance.
- A Sustainability Strategy for the project is recommended to guide the next phase of design. It can provide guidance on carbon design principles and ISCA to create consistency across all aspects of the project in relation to environmental sustainability.

3 Results and conclusions

This chapter summarises key results for the whole of life carbon assessment for Auckland Light Rail (ALR). For more detailed interpretation of the results of this assessment refer to Chapter 9.

The results are illustrated in a carbon emissions profile which documents the cumulative emissions for different combinations of the emission sources from ALR compared to the do minimum option. Figure 3-1 illustrates the sources assessed for each profile. Note source 6 and 7 (urban design elements) have been assessed qualitatively outside the three profiles.

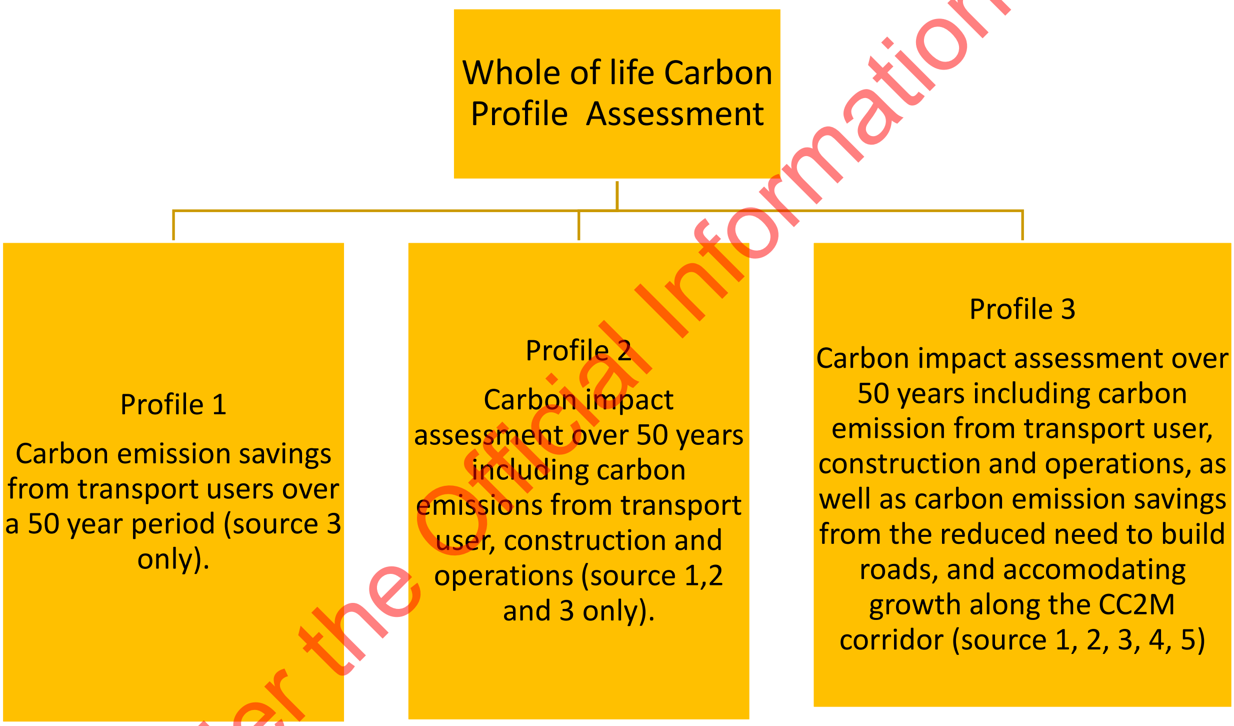

Figure 3-1: Factors assessed for the three Whole of Life Carbon Profiles for ALR

3.1 How to interpret the profiles

Results are based on the information available at this early project stage and are indicative only.

To understand the whole of life carbon impact of the five ARL options, three discrete carbon profiles have been developed to illustrate cumulative emissions for each ALR option, compared to the do minimum option, from base year 2018, as used in MSM, and up to 2080.

For this carbon profile assessment, the design life of ALR assets have been assumed to be 100 years.

It is important to note that the MSM model considers the projected changes in Auckland's electric vehicle fleet composition for VEPM 6.1. See Chapter 9.8.3 for more details on VEPM 6.1.

For the purposes of developing a cumulative profile three assumptions have been made.

- It is assumed that the emissions every year from 2031 to 2050 have the same emissions as modelled in in 2031.
- Emissions for years after 2051 and up to 2081 will be the same as the emission modelled for 2051.
- The electric vehicle fleet composition from 2018 to 2051 follow the VEPM 6.1 projections. The electric fleet profile for years post 2050 remains the same at the percentage in 2050 (69%).

3.2 Whole of Life Carbon Profile 1

Figure 3-2 illustrates that options 2a result in the highest carbon emission savings when compared to the do minimum option, when assessing transport user emissions sources only. The emissions from each option were subtracted from those of the do minimum option illustrating "negative" carbon emissions (which represents the carbon emissions saved for each option). The steeper the graph, the faster the carbon emissions savings are realised over the life of the ALR asset for each the option.

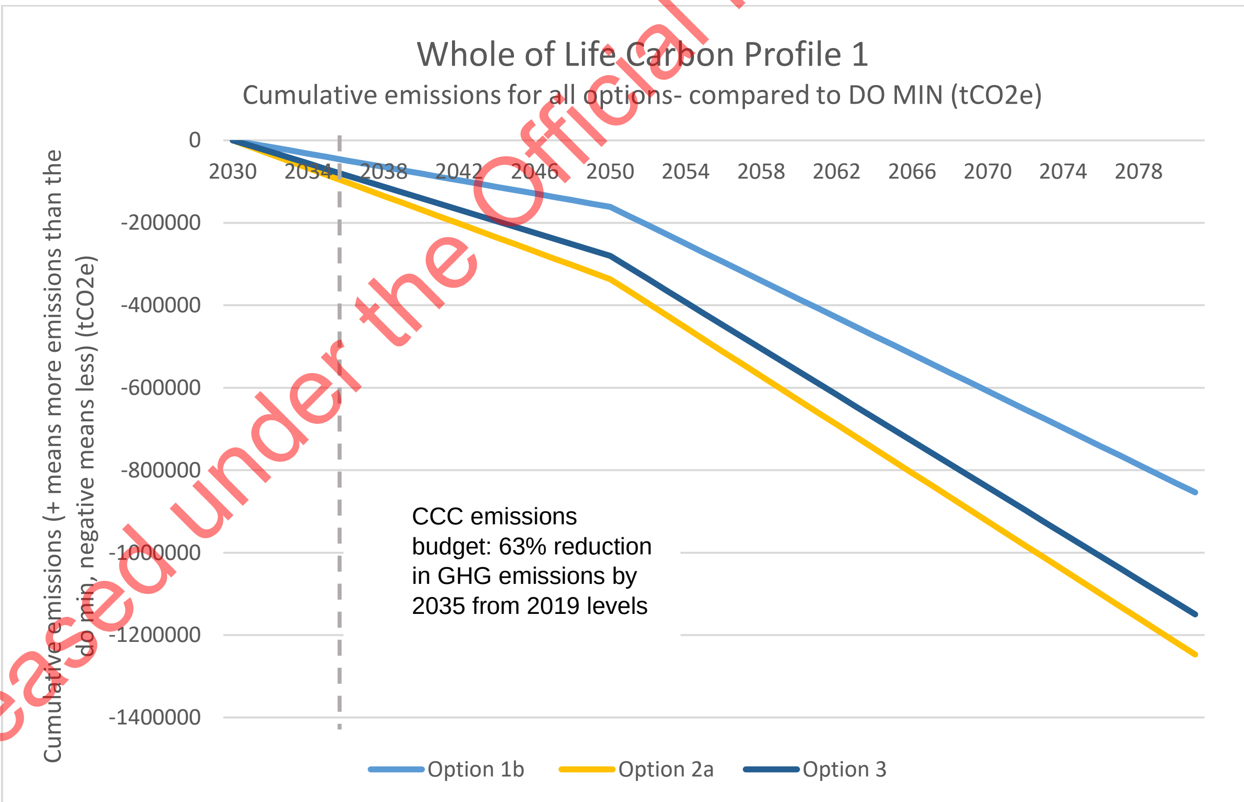

Figure 3-2: WoL Profile 1 showing transport system emissions based on the 2051 emissions relative to the do minimum (tCO2e/year).

Figure 3-3 illustrates the 2051 emissions for each ALR option compared to the do minimum option.

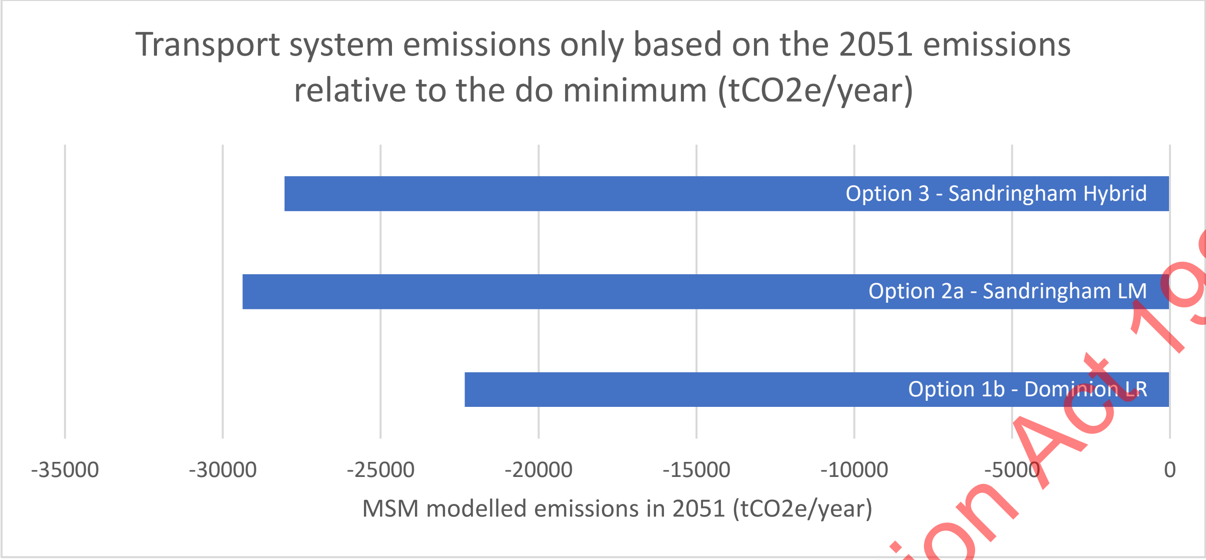

Figure 3-3: 2051 emissions for each ALR option compared to the do minimum. Source: MSM model outputs dated 12 August 2021.

3.3 Whole of life carbon Profile 2

This assessment was undertaken by compiling the cumulative carbon sources and carbon savings sources (sources 1 to 5) to illustrate ALR project carbon emissions over a time-lapse profile. This assessment used the carbon emissions / year metrics from the MSM model.

Figure 3-4 shows the cumulative carbon emissions (construction, operation, and transport) for each of the ALR options, as compared to the do minimum option. A construction period of 7 years was assumed for all options and operational emissions were assumed to be constant throughout the 50-year period. Carbon emissions increase due to the construction period from 2023 but are offset from 2030 due to the benefits of mode shift and reduced VKT, as a result of the system becoming fully operational. Figure 3-4 illustrates that the ALR light rail options perform better than light metro options over the 50-year period, since they can inherently reduce more carbon emissions than the do minimum option and realise total carbon reduction benefits earlier than light metro options. Relative to the do minimum option, it can be expected that the carbon reduction benefits from light rail options will start to be realised by approximately 2051 (for Option 1b), whereas light metro carbon reduction benefits will start to be realised later, from around 2060.

There are embodied carbon impacts as a result of constructing each option due to the use of concrete and other materials. Due to the scale of construction of the underground light metro stations, the embodied carbon for the Light Metro and Hybrid options are significantly higher than for the Light Rail option.

Importantly, all options result in net reductions in carbon over the 50-year assessment period, with ongoing benefits past this assessment period. As shown in Figure 3-4, parity of carbon emissions, when compared to the do minimum scenario, from constructing the Light

Rail Option 1b is achieved after approximately 20 years of operation and the Light Metro Option 2a takes approximately 30 years.

Assumptions:

- The transport user emissions/year for modelled outputs for 2018 were assumed for each year until 2030.
- The transport user emissions/year for modelled outputs for 2030 were assumed for each year until 2051
- The transport user emissions/year for modelled outputs for 2050 were assumed for each year after 2051.
- A construction period of 7 years was assumed for all options and operational emissions were assumed to be constant throughout the 50-year period. Construction is assumed to begin in 2023.

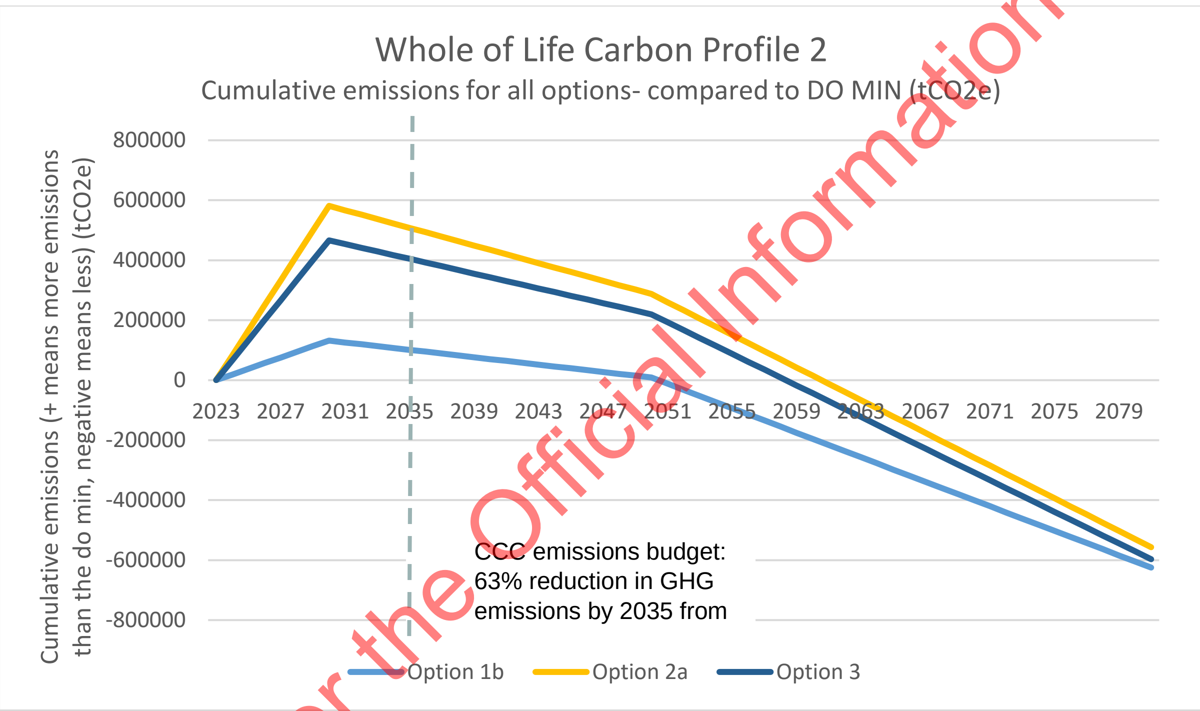

Figure 3-4: WoL Profile 2 showing total carbon emissions (transport, construction, and operation) for each option as compared to the do-minimum option

Compared to the Do Minimum base case scenario by year 2081:

- The Dominion Light Rail option (1b) reduces carbon emissions by around 620,000 tCO_2e.
- The Sandringham Light Metro option (2a) reduces carbon emissions by around 560,000 tCO_2e.
- The Hybrid option (3) reduces carbon emissions by around 600,000 tCO_2e.

3.4 Whole of Life Carbon Profile 3

Taking into account the household energy use and road construction factors contribute to significantly more carbon benefits for ALR when compared to the do minimum.

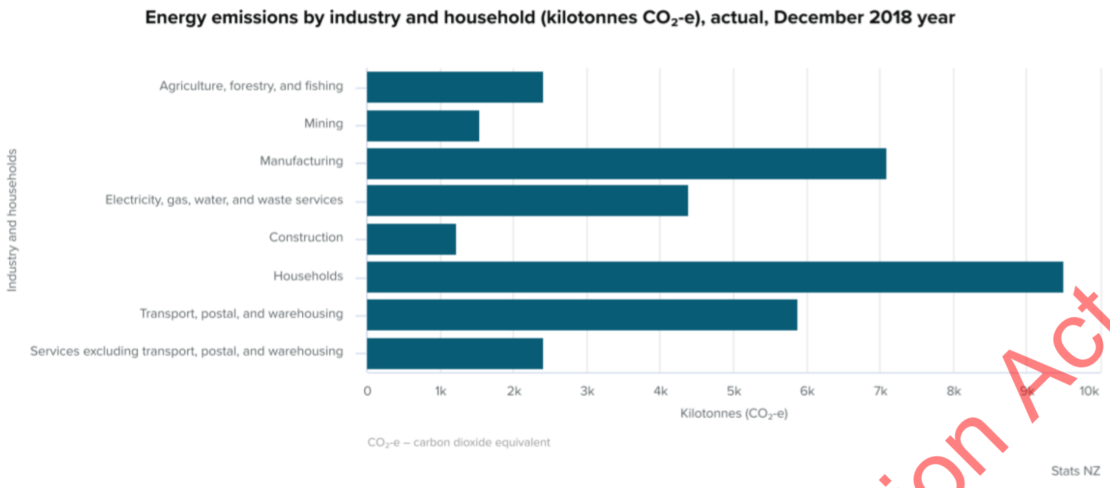

Figure 3-5: Carbon energy emissions by industry and household in NZ. Source: Stats NZ[5]

Figure 3-5 shows that a significant proportion of carbon emissions come from household energy use. This highlights the importance of including household energy use to develop Profile 3. A significant amount to emissions from households suggests that the need to reduce travel is key to reducing carbon emissions in NZ. This reinforces the need to consider the Avoid interventions as outlined in the Transport Emissions Pathway to Net Zero by 2050.

Similarly, to WoL Carbon Profile 2, Figure 3-6 illustrates the cumulative emissions (sources 1,2,3,4 and 5) for each of three ALR options compared to the do minimum option. Similar assumptions from Carbon Profile 2 were adopted in Carbon Profile 3.

Additional factors applied to all three ALR option included in WoL Carbon Profile 3 compared to Profile 2 include:

- Reduced carbon emissions due to the avoided need to construct roads and car parks, as a result of reduced demand for private vehicle travel. Emissions savings from construction of fewer roads and carparks range from 29,000 tCO2e to 31,000 tCO2e. These are based on calculations in Chapter 9.7.
- Reduced carbon emissions from the provision of higher density urban residential development in urban brownfield areas (adjacent the ALR alignment), relative to continuing to build singe detached dwellings in fringe greenfield areas of Auckland. Carbon emissions savings from high-density housing are primarily derived from savings in energy consumption and range from 4,000 tCO2e to 7,000 tCO2e per year.

Figure 3-6 illustrates that when compared to the do minimum option, carbon reduction benefits for ALR light rail options are realised by 2041. Carbon reduction benefits from the light metro and hybrid options are realised by the early 2050's (between 2052 and 2054). In contrast to WoL Carbon Profile 2, this assessment shows that by 2081, the light metro and hybrid option achieve greater overall carbon reduction benefits.

[5] https://www.stats.govt.nz/experimental/greenhouse-gas-emissions-industry-and-household-september-2020-quarter

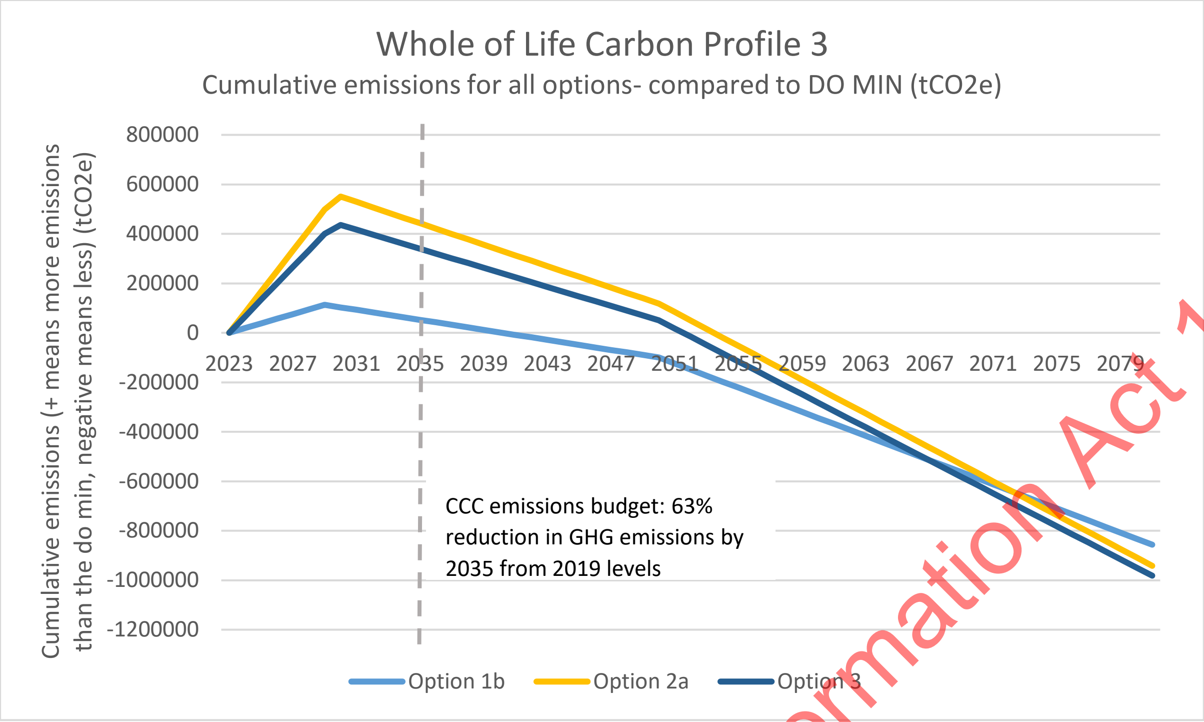

Figure 3-6: WoL Profile 3 showing the total carbon emissions (transport, construction, operation, road savings, energy savings) for each option when compared to the do minimum option.

Compared to the Do Minimum base case scenario by 2081:

- There are greater overall carbon emission benefits for each of the shortlisted options
- The Dominion Light Rail option (1b) reduces carbon emissions by around 860,000 tCO_2e
- The Sandringham Light Metro option (2a) reduces carbon emissions by around 940,000 tCO_2e.
- The Hybrid option (3) reduces carbon emissions by around 980,000 tCO_2e.

3.5 Whole of life Carbon MCA Options assessment outcome

The table below documents the impact of the six carbon emission emitter and carbon savings analysed on each of the three ALR options.

To understand the whole of life carbon impact of all three cases, the cumulative carbon impact has been assessed on WoL Profile 3 (which captures five of the 7 sources). WoL Profile 3 and the qualitative urban assessment (source 6) has been used to determine a preferred option from the perspective of a carbon emissions reduction outcome.

Option 1B LRT Dominion	**Construction emissions (source 1)** - Option 1b produces a lower amount of carbon emissions than light metro options, mainly because of the smaller station sizes that are predominantly above ground. The majority of construction emissions come from the large number of bridge structures required for the option. The option scored better than the hybrid and light metro options for cycle infrastructure provision. **Operational emissions (source 2)-** Operational emissions are higher for this option due to the longer track distance, which creates more kilometres travelled by the light rail system and requires more energy for network operations.

	Transport system carbon emissions (source 3) – Option 1b provides less capacity/hour than the light metro and hybrid options. It has more stations along the proposed alignment compared to the metro and hybrid options. The option scored better than the hybrid and light metro options for cycle infrastructure provision. The carbon emissions from the MSM modelling show carbon emissions from transport across Auckland producing 1,684,000 tCO2e/year, with option 1b with the highest carbon emissions. The mode shift from car to PT/active modes was 5.0%. More general traffic roads are likely to be removed for light rail options than metro and hybrid options. This is represented in Carbon Profile 3. **Reduced road construction savings (source 4)* -** Option 1b results in 29,127 tCO2e savings, Option 2a at 30,745 tCO2e savings, and Option 3 at 30,369 tCO2e savings. Option 2a create slightly more emission savings than Option 3 and 1b. **Housing energy savings (source 5**) – all options encourage higher density housing typologies along the ALR corridor. Options 2a (6,947 tCO2e/year) and 3 (6,947 tCO2e/year) are along the same alignment so they experience the same increase in population. They both have a higher population after ALR than Option 1b, so result in higher energy emission savings than Option 1b (3,970 tCO2e/year). **Urban form emissions savings (source 6)** – all options adopt transit led development across the ALR corridor, and mixed-use zoning.
Option 2A Light Metro Sandringham	**Construction emissions (source 1)** - Option 2a produces the highest amount of carbon emissions, mainly because of the higher number of stations that are located underground. The construction of underground stations is carbon emissions intensive due to tunnelling and concrete material volumes. **Operational emissions (source 2)-** The track distance for this option is lower than the Sandringham light rail option, but the capacity of the light metro vehicle is higher, and the services operate at higher frequencies which requires more energy for network operations. **Transport system carbon emissions (source 3)** – Option 2a performed better than light rail options in terms of supporting high density urban development and has more capacity/hour to encourage mode shift. It is likely to provide more general traffic lanes than the light rail options and the hybrid option. The carbon emissions from the MSM modelling show carbon emissions from transport across Auckland producing 1,677,000 tCO2e/year, with option 2a with the lowest overall carbon emissions. The mode shift from car to PT or active modes was 6.5%. **Reduced road construction and parking savings (source 4)* –** Option 1b results in 29,127 tCO2e savings, Option 2a at 30,745 tCO2e savings, and Option 3 at 30,369 tCO2e savings. Option 2a create slightly more emission savings than Option 3 and 1b. **Housing energy savings (source 5**) – all options encourage higher density housing typologies along the ALR corridor. Options 2a (6,947 tCO2e/year) and 3 (6,947 tCO2e/year) are along the same alignment so they experience the same increase in population. They both have a higher population after ALR than Option 1b, so result in higher energy emission savings than Option 1b (3,970 tCO2e/year). **Urban form emissions savings (source 6)** – all options adopt transit led development across the ALR corridor, and mixed-use zoning.
Option 3 Light Rail Hybrid	**Transport system carbon emissions (source 3)** – Option 3 performs better than light rail options but slightly worse than light metro options in terms of supporting urban density uplift. The key

	advantage of option 3 over options 2a is its ability to remove space from road corridors for cars and make driving a less attractive option. However, in this regard, light rail options perform better. Mode shift from this option is higher than light rail options but lower than light metro options. The carbon emissions from the MSM modelling show carbon emissions from transport across Auckland producing 1,678,000 tCO2e/year, with higher carbon emissions than light metro, but lower than light rail options. **Reduced road construction savings (source 4)* -** Option 1b results in 29,127 tCO2e savings, Option 2a at 30,745 tCO2e savings, and Option 3 at 30,369 tCO2e savings. Option 3 create slightly less emission savings than Option 3. **Housing energy savings (source 5**) – all options encourage higher density housing typologies along the ALR corridor. Options 2a (6,947 tCO2e/year) and 3 (6,947 tCO2e/year) are along the same alignment so they experience the same increase in population. They both have a higher population after ALR than Option 1b, so result in higher energy emission savings than Option 1b (3,970 tCO2e/year). **Urban form emissions savings (source 6)** – all options adopt transit led development across the ALR corridor, and mixed-use zoning.
Option Preference	**All carbon emissions** • Construction emissions (source 1) - Option 1b based on the results in Chapter 10.5. • Operational emissions (source 2) – Option 3 based on results in Chapter 10.4. • Transport system carbon emissions (source 3) - Option 2a based on the results in Chapter 10.6. • Reduced road construction savings (source 4) – Option 2a based on results in Chapter 10.7 • Housing energy savings (source 5) – Option 2a and 3 based on results in Chapter 10.8. • Urban form emissions savings (source 6) – all options rank the same based on the results in Chapter 8.1. • The cumulative emissions across all five carbon sources result in emission savings when compared to the do minimum option. • Taking into account all 5 whole of life carbon emission sources the preferred option is option 3 based on WoL Profile 3. It results in more emission savings by 2081.

**Modelled based on peak travel demand for 2051*

3.6 Overall project carbon performance assessment outcome

The outcome of the Overall Project carbon performance showed that there are some emission reduction interventions out of control of the project (i.e. controlled by other government bodies) that have not been adopted that would result in emission savings due to the ALR project. The full list of interventions have been illustrated in the Intervention Suite in Chapter 7.3. Majority of the emission reduction interventions that can be controlled by the project have been adopted. As detailed design information is produced the level of emission reduction potential will be able to be assessed.

The emission reduction potential for the refined options and do minimum based for the suite of interventions outlined in Chapter 7.3 are shown below. The key is shown in the table below.

Table 1: Overall Project carbon performance - emission Reduction Potential Rating

	Do min	Option 1b	Option 2b	Option 3
Emission reduction potential rating	2.3	3.0	3.1	3.0

Rating Description	Emission reduction potential rating
Emission increasing potential	0
Negligible emission reduction potential	1
Low to medium emission reduction potential	2,3,4
Medium to high emission reduction potential	5,6,7

4 Policy Context

ALR has been developed against a background of policy expectations to accelerate decarbonization of transport in Auckland. Below are several relevant policy documents that apply to the ALR project It captures how the ARL project takes these policies into account through the busines case process.

Toitu te Taiao Our Sustainability Action Plan - Workstream 1 focuses on planning and investment levers to reduce carbon emissions. These levels are included in Arup GHG User Emissions Model used to assess transport system emissions activity 1 (emission reduction potential).

Auckland Climate Plan – reduce emissions by 50% by 2030 (from 2016 levels) and achieve net zero emissions by 2050. These targets have been considered when reflecting on the emission profile results.

Broader Outcomes Procurement Strategy – transitioning to a net-zero emissions economy. This will inform the ISCA Strategy and Assessment

The Ministry of Transport's 'Hīkina te Kohupara – Kia mauri ora ai te iwi - Transport Emissions: Pathways to Net Zero by 2050 (Green Paper) – Outlines the Avoid/Shift/Improve strategy which was used to inform the ASI Assessment in Chapter 8.

Emission Reduction Plan - policies and strategies to reduce emissions and increase removals to meet the emissions budget for each sector including transport.

5 Environmental context

The data in Table 2 has been extracted from the Waka Kotahi StoryMap Database. The table shows the tail pipe (transport user) emissions along the road corridors for the proposed five options. Cross sections for the majority of these roads have more space dedicated to passenger vehicles lanes, parking, and bus lanes. This means a significant proportion of the road corridor caters to an existing NZ fleet that produces carbon emissions. This was used to inform the baseline carbon emissions.

Table 2: Carbon Emissions along the ALR corridors. Source: Storymaps

Road corridor	**CO2 t/km/year**	
	Low	**High**
Symonds St	1,344	2,245
Queen St	1,027	1,690
Ian McKinnon Dr	2,414	2,489
Dominion Rd	1,794	1,966
Sandringham Rd	1,346	1,626
SH20 (Mount Roskill to Onehunga)	3,012	4,934
Onehunga Mall	1,272	1,570
Neilson St	966	2,677
Bader Dr	753	1,934
SH20 (Mangere)	3,945	5,340
SH20a	1,653	2,087

6 Alignment to the IBC investment objectives and benefits

The GPS 2020[6] alignment activities for carbon are:

- Percentage reduction in private vehicle kilometres travelled
- Percentage reduction in CO_2 emissions

These metrics have been included in the carbon assessment methodology documented in this report. These have been documented in Chapter 9.

The GPA alignment priorities require spatial and geographical boundaries of the activity to be defined. These have been documented in Chapter 9.3.

7 ASI assessment for transport user emissions

The Arup GHG Tool has a catalogue of transport user emission interventions categorised by NLTP work categories, ASI category, owner, and emission reduction potential.

[6] Investment Prioritisation Method for the 2021–24 National Land Transport Programme Dec 2020

There are four types of interventions in the catalogue available to reduce transport user emissions are shown in Figure 7-1.

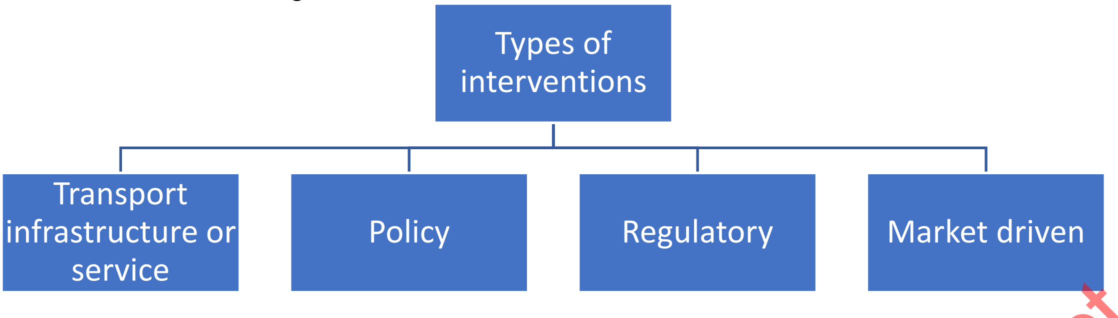

Figure 7-1: Transport user emission reduction intervention categories to reduce transport user emissions

There are several groups who have control over the interventions as shown in Figure 7-2.

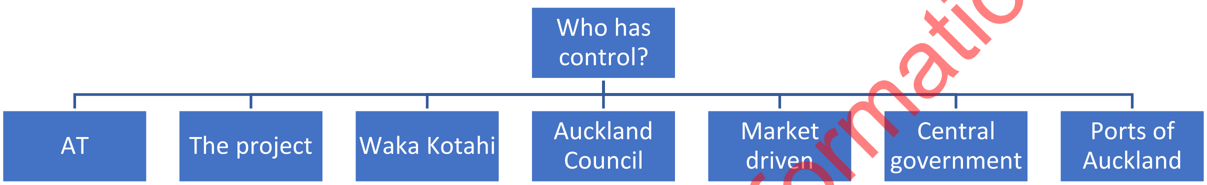

Figure 7-2: Organisations who control different transport user emission reduction interventions

The transport user emission reduction interventions from Arup GHG Tool considered in the ALR transport user carbon assessment is outlined in the table below. Table 3 also illustrates who is owner of the intervention and the Avoid, Shift, or Improve category of the intervention. Majority of these interventions where the same across all the five options and the do minimum option. The blue rows represent avoid interventions, green rows represent the improve interventions, yellow rows represent the shift interventions.

Table 3: Transport user emission reduction interventions classified by Avoid, Shift, or Improve and owner

Owner/who has control	ASI classification	Transport user emission reduction interventions
AT	Avoid	Rideshare matching and incentives
Auckland Council	Avoid	Urban planning codes and practices
The Project	Avoid	Transit oriented development (TOD) zoning - mixed use (residential and zoning) vs single use complemented by higher population density
Central Government, AT, and Auckland Council	Avoid	Cordon and/or network pricing
Market	Avoid	Flexitime schedules
Market	Avoid	Compressed work weeks and telework, work from home policy by commercial businesses
Market	Avoid	Car-sharing programmes
Waka Kotahi	Avoid	Motor fuel taxes
AT	Improve	Low emission public transport
AT	Improve	Electric bus fleet composition
AT	Improve	Transport concessions

Auckland Council	Improve	Charging infrastructure for ev - residential
EECA	Improve	Charging infrastructure for ev - public
Market	Improve	Charging infrastructure for ev - commercial
Market	Improve	Commercial delivery fleet composition
Ports of Auckland	Improve	Electric road vehicles
Waka Kotahi	Improve	Efficient cars and motorcycles
Waka Kotahi	Improve	Efficient trucks
Waka Kotahi	Improve	Support uptake of low emission vehicles
The Project	Shift	Roadway capacity expansion
AT	Shift	Support micro mobility shared services
AT	Shift	Parking pricing
AT	Shift	Managing on-street parking supply
Auckland Council	Shift	Parking requirements
The Project	Shift	Public transport service improvements (frequency, efficiency, reliability)
The Project	Shift	Light rail, metro rail and commuter rail systems
The Project	Shift	Bus rapid transit
The Project	Shift	New and improved sidewalks and pedestrian crossings.
The Project	Shift	Bicycle infrastructure, networks, and support programmes
The Project	shift	Removing road capacity for passenger travel

Of these, the interventions with the most material impacts to the transport user emissions across the five options are outlined in Table 4 below. These interventions where those that represented the main differences across the five options.

Table 4: Most material transport user emission reduction interventions for ALR IBC

Interventions	ASI	Metrics that influence transport user emissions
Transit oriented development (TOD)	Avoid	• Increased development density via GFA uplift within the 800m catchment,
Urban planning	Avoid	• Equal split in mixed use zoning via GFA uplift for residential and employment zones, removal of general traffic road capacity.
Light rail, metro rail and commuter rail systems	Shift	• An attractive PT via light rail/light metro would promote mode choice to PT and away from the car based on the capacity, travel time, number of stations provided.
Removing road capacity for passenger travel	Shift	• Fewer road capacity for general traffic means PT and active modes become more attractive options.
Bus rapid transit	Shift	• Attractive bus rapid transit to support connection to the light rail/light rail system (number of stations and urban interchanges along the proposed alignment) would promote interconnectivity to other transit and active modes.

Bicycle infrastructure	Shift	• Provision of improved cycle infrastructure and connection to existing cycle network promotes the use of low emission modes.

ASI ASSESSMENT CONCLUSIONS

The predominant ASI strategy used in ALR to reduce transport user emissions are shift and avoid which utilised land use and transport design features to influence emission reduction from transport users.

It is important to recognise that the ALR Project team do not have control over majority of the interventions, and so it is important to have a coordinated effort across these groups. It is the collective decisions across these groups that will maximise ALR's potential in reducing emissions in Auckland.

8 Overall carbon performance assessment

8.1 Urban context carbon assessment

Currently, Auckland's urban form has been characterized by sprawl, with relatively high levels of development in greenfield sites and in areas further away from areas of employment, education, or recreation. This has driven an increase in carbon emissions, both from an increase in distance travelled and from the need to construct new infrastructure to service these new developments (such as roads, water infrastructure etc). Since the introduction of the Auckland Unitary Plan, more development has been occurring in existing brownfield areas. Residents in brownfield areas travel smaller distances and have better access to sustainable forms of transport, which results in a lower transport carbon emissions footprint. However, to keep up with population growth and demand, a significant proportion of new housing developments are still expected to occur in greenfield areas, which will continue to drive an increase in carbon emissions.

The proposed scheme is expected to play a significant role in shaping Auckland's urban form, and act as a trigger for urban redevelopment in brownfield areas. More medium to high density developments are expected to occur in the corridor, instead of in new greenfield areas, which will be accompanied by a change in land use. This change in land use and urban form, accompanied by improved public realm, streetscapes and open space is expected to encourage mode shift, with people choosing to travel by more sustainable forms of transport. This forms the basis for some of the most significant benefits of light rail, namely, the scheme will help promote sustainable urban form and reduce Auckland's carbon footprint.

The urban carbon emission saving interventions adopted in the ALR IBC are shown below. Those classified as no are either due lack of design detail in IBC stage, out of scope for the urban design business case team.

Document	Owner/who has control	Emission reduction intervention type	Urban emission reduction intervention	Adopted for ALR IBC
Business Case Urban Design	The Project	Urban design	Transit oriented development (TOD) Zoning - mixed use (residential and zoning) vs single use complemented by higher population density	yes
District Green Freight Plan	Auckland Council	Urban regulatory	Regional freight distribution centres, inland ports, and logistics parks	no
Business Case Urban Design	The Project	Urban design	Higher density housing	yes
Business Case Urban Design	The Project	Urban design	Higher development density and mixed-use zoning	yes
Business Case Urban Design	The Project	Urban design	Pedestrian friendly environment	no
Business Case Urban Design	The Project	Urban design	Attractive public realm to encourage mode shift from the car	no
District Plan/Master Plan	AT	Urban regulatory	Car free zones & restricted traffic streets or pedestrian only streets	no
District Plan/Master Plan	AT	Urban regulatory	Managing on-street parking supply	no
District Plan/Master Plan	Auckland Council	Urban regulatory	Parking requirements	no
District Plan/Master Plan Parking strategy	AT	Urban regulatory	Parking pricing	no
District Plan/Structure Plan	Auckland Council	Urban regulatory	Urban planning codes and practices	no

8.1.1 Results

The Project is adopting majority of the carbon reduction interventions they have control over, however majority of the interventions outside of the control of the Project team have not been adopted.

8.2 Embodied carbon emissions from the Auckland EV fleet

Electric vehicles (EVs) are often considered a potential solution to mitigate greenhouse gas GHG) emissions originating from personal transport vehicles and public transport. However, to assess the WoL impact of emission from ALR, it is important to consider the embodied carbon emissions from the Auckland fleet from the assumed first year of operations 2031. Figure 8-1 shows the typical whole of life GHG emissions factors for ICEV and EV vehicles.

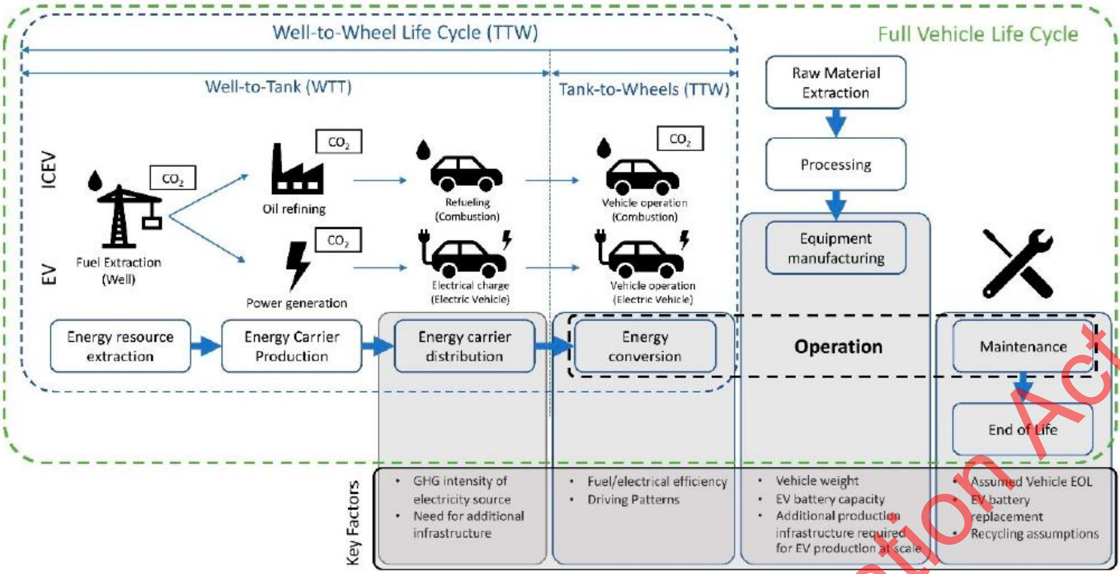

Figure 1. Illustration of a vehicle life cycle (adapted from [5,6]).

Figure 8-1: Illustration of a vehicle life cycle for ICEV and EVs. Source: Review and Meta-Analysis of EVs: Embodied Emissions Report[7]

The most significant factors of emissions over the whole life of an EV is the GHG grid intensity for the Well to Wheel life cycle stage are the charging activities.

Figure C.1 Generation by type

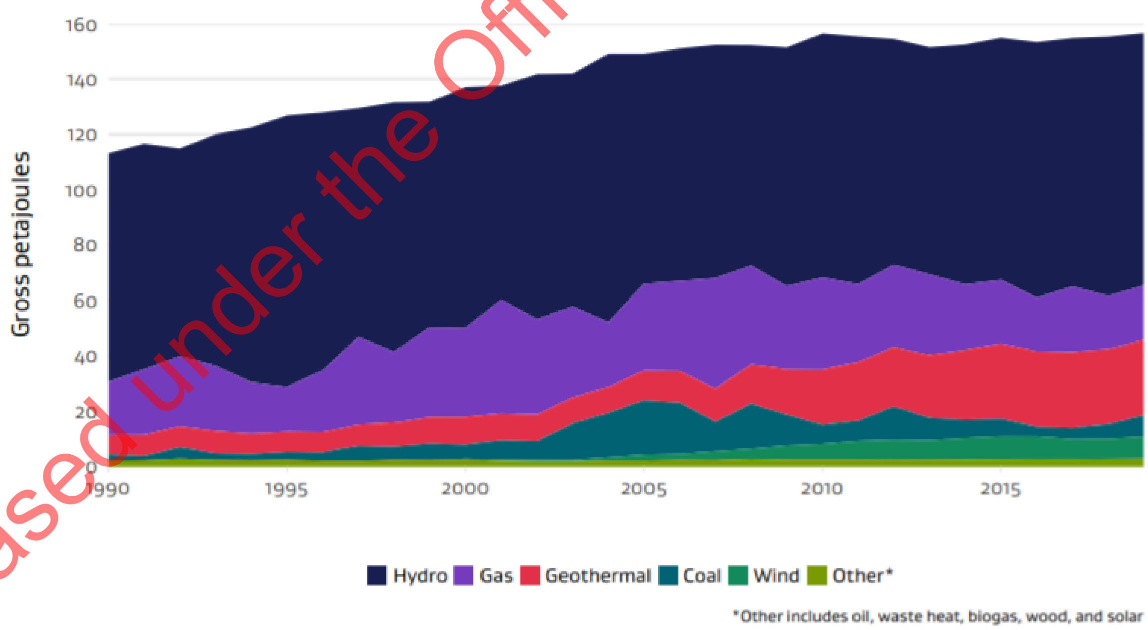

Figure 8-2: Electricity generation type. Source: Energy use in NZ 2020 from MBIE[8]

It is important to consider power generation for the charging activities of EV especially as the NZ electric fleet grows. Transport accounts for 40% of the national energy demand at a 0.3%

[7] https://www.mdpi.com/2071-1050/12/22/9390/pdf
[8] https://www.mbie.govt.nz/dmsdocument/11679-energy-in-new-zealand-2020

electric car fleet composition outlined in VEPM 6.1[9]. Figure 8-2 shows the energy generation mix in NZ. In 2020 61% of the electricity grid was from zero emission sources hydro, solar and wind[10]. Overall, the GHG grid intensity in 2020 was 0.101 gCO2e/MWh.

8.2.1 Results

A study conducted case studies globally to determine the average embodied emissions from electric vehicles compared to petrol and diesel vehicles shown in Figure 8-3. Electric vehicles have higher GHG emissions in the production phase (vehicle and battery production). However, it is important to note that majority of the NZ fleet are imported. This means the majority of these production embodied emissions are likely to be created offshore.

Table 7. Mean, standard deviation (SD), and population size *n* of emissions from production, WTW, maintenance, EOL, and energy efficiency from all studies reviewed.

		Production *(tCO_2 eq.)*	**Energy Efficiency** *(EV: kWh/100 km ICEV: L/100 km)*	**WTW Emissions** *(gCO_2eq/km)*	**Maintenance** *(gCO_2eq/km)*	**EOL** *(tCO_2eq)*
BEV	Mean	10.8	16.7	132.2	10.1	0.2
	SD	2.38	3.15	107.1	5.06	1.55
	n	24	23	40	14	13
Petrol	Mean	6.6	7.6	237.1	12	0.4
	SD	2.01	2.12	63.64	5.55	1.05
	n	18	17	23	12	14
Diesel	Mean	6.1	5.2	154.3	10.1	−0.6
	SD	1.25	1.03	32.7	4.82	1.06
	n	6	5	8	4	4

Figure 8-3: Average embodied emissions from electric vehicles compared to petrol and diesel vehicles Source: Review and Meta-Analysis of EVs: Embodied Emissions and Environmental Breakeven [11]

8.3 Carbon emission reduction intervention suite

The table below captures the emission reduction interventions, the intervention type, which organisation has control to adopt the intervention, and the document name the decision to adopt the intervention would be captured.

The suite can be used to determine which emission reduction activities can be adopted not only by the project design team but by the wider ecosystem which all inform the carbon performance of ALR.

Emission reduction interventions	Document	Owner/who has control	Intervention Type
Support micro mobility shared services	District micro mobility plan	AT	Policy

[9] https://www.mbie.govt.nz/dmsdocument/11679-energy-in-new-zealand-2020
[10] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/
[11] https://www.mdpi.com/2071-1050/12/22/9390/pdf

Rideshare matching and incentives	On demand transport regional roadmap	AT	Policy
Low emission public transport	ZEB PT transition roadmaps, NZ ZEB Working Group	AT	Policy
Bus fleet composition	ZEB PT transition roadmaps, NZ ZEB Working Group	AT	Policy
Transport concessions	Council fare/discount strategy	AT	Regulatory
Car free zones & restricted traffic streets in pedestrian only streets	District Plan/Master Plan	AT	Urban regulatory
Managing on-street parking supply	District Plan/Master Plan	AT	Urban regulatory
Parking pricing	District Plan/Master Plan Parking strategy	Auckland Council	Urban regulatory
Charging infrastructure for EV - residential	Council building code requirements	Auckland Council	Regulatory
Tax incentives for alternative mode use and disincentives for employer provided free parking	Council low emission travel strategy	Auckland Council	Regulatory
Freight pricing and management	District Green Freight Plan	Auckland Council	Regulatory
Regional freight distribution centres, inland ports, and logistics parks	District Green Freight Plan	Auckland Council	Urban regulatory
Parking requirements	District Plan/Master Plan	Auckland Council	Urban regulatory
Urban planning codes and practices	District Plan/Structure Plan	Auckland Council	Urban regulatory
Cordon and/or network pricing	Council Emission Reduction Plan (Transport and land use elements)	Central Government, Auckland Transport and Auckland Council	Policy

Congestion pricing (e.g. Peak period) new (N) and existing €	Council congestion pricing strategy	Council	Policy
Fare system improvements	Business Case Transport Design	Council	Transport service/infrastructure
Car-sharing programmes	Car sharing transport regional roadmap, market driven	Council and Market	Regulatory
Charging infrastructure for EV - public	Council EV uptake strategy, EV Charging Roadmap	EECA	Regulatory
Efficient ships	Green Maritime import and export regulations, Low Emission Port Strategy	Maritime NZ, Ports	Regulatory
Flexitime schedules	Market driven	Market	Market driven
Compressed work weeks and telework, Work from home policy by commercial businesses	Market driven	Market	Market driven
Charging infrastructure for EV - commercial	Council building code requirements	Market	Regulatory
Commercial delivery fleet composition	Council Green Freight plan (urban form and transport network elements)	Market	Regulatory
Biofuels	National Green Freight Plan	Ministry of Transport	Regulatory
Intra- and inter-regional low carbon freight modes	District Green Freight Plan	Mot, Auckland Council, EECA	Regulatory
Electric road vehicles	EV Uptake strategy, NZTA Green car import regulations, NZTA Clean Car standards	Ports of Auckland	Policy
Public transport service improvements (frequency, efficiency, reliability)	Business Case Transport Design	The Project	Transport service/infrastructure
Public transport service improvements (frequency, efficiency, reliability)	Business Case Transport Design	The Project	Transport service/infrastructure

Light rail, metro rail and commuter rail systems	Business Case Transport Design	The Project	Transport service/infrastructure
Light rail, metro rail and commuter rail systems	Business Case Transport Design	The Project	Transport service/infrastructure
Bus rapid transit	Business Case Transport Design	The Project	Transport service/infrastructure
Public transport integration in priority corridors	Business Case Transport Design	The Project	Transport service/infrastructure
Public transport integration in priority corridors	Business Case Transport Design	The Project	Transport service/infrastructure
New and improved sidewalks and pedestrian crossings.	Business Case Transport Design	The Project	Transport service/infrastructure
New and improved sidewalks and pedestrian crossings	Business Case Transport Design	The Project	Transport service/infrastructure
Traffic calming	Business Case Transport Design	The Project	Transport service/infrastructure
Bicycle infrastructure, networks, and support programmes	Business Case Transport Design	The Project	Transport service/infrastructure
Intelligent transportation systems	Business Case Transport Design	The Project	Transport service/infrastructure
Traffic management	Business Case Transport Design	The Project	Transport service/infrastructure
Roadway capacity expansion	Business Case Transport Design	The Project	Transport service/infrastructure
Roadway capacity expansion	Business Case Transport Design	The Project	Transport service/infrastructure
Roadway capacity expansion	Business Case Transport Design	The Project	Transport service/infrastructure
Multi modal connectivity	Business Case Transport Design	The Project	Transport service/infrastructure

(covered in Public transport integration in priority corridors subcategory)			
Public transport service improvements (frequency, efficiency, reliability)	Business Case Transport Design	The Project	Transport service/infrastructure
Transit oriented development (TOD) Zoning - mixed use (residential and zoning) vs single use complemented by higher population density	Business Case Urban Design	The Project	Urban design
Higher density housing	Business Case Urban Design	The Project	Urban design
Higher development density and mixed-use zoning	Business Case Urban Design	The Project	Urban design
Pedestrian friendly environment	Business Case Urban Design	The Project	Urban design
Attractive public realm to encourage mode shift from the car	Business Case Urban Design	The Project	Urban design
Support uptake of low emission vehicles	Council EV uptake strategy, NZTA Green car import regulations, NZTA Clean Car standards	Waka Kotahi	Policy
Motor fuel taxes	Council fuel tax regulations	Waka Kotahi	Policy
Efficient cars and motorcycles	NZTA Green car import regulations	Waka Kotahi	Policy
Efficient trucks	NZTA Green car import regulations, EECA support industry to transition to green freight, Green Freight mot Policy	Waka Kotahi	Policy

Road user fees for new(N) and existing roads	RUC Regulations	Waka Kotahi	Policy
Motor vehicle registration fees and taxes	Vehicle registration regulations	Waka Kotahi	Regulatory
Motor vehicle quota systems	Vehicle registration regulations	Waka Kotahi	Regulatory
License plate restrictions	Vehicle registration regulations	Waka Kotahi	Regulatory
Eco-driving and vehicle maintenance	Vehicle registration regulations	Waka Kotahi	Regulatory
Reduce national speed limits on motorways	National Speed Management Plan	Waka Kotahi	Transport service/infrastructure
Travel demand management	Business Case Transport Design	Waka Kotahi	Transport service/infrastructure

The emission reduction potential for the refined options and do minimum based for the suite of interventions outlined in Chapter 7.3 are shown below. The key is shown in the table below.

Table 5: Overall Project carbon performance - emission Reduction Potential Rating

	Do min	Option 1b	Option 2b	Option 3
Emission reduction potential rating	2.3	3.0	3.1	3.0

Rating Description	Emission reduction potential rating
Emission increasing potential	0
Negligible emission reduction potential	1
Low to medium emission reduction potential	2,3,4
Medium to high emission reduction potential	5,6,7

9 Whole of life carbon emissions assessment

A secondary WoL carbon assessment was undertaken in September 2021 to inform the IBC design for the ALR project. This assessment was conducted only for Options 1b, 2a and 3. This report considers what the wider network impact be in the longer term across Auckland, in order to gain an understanding of what the full long-term effects might be. Five IBC options for ALR are considered within this report as well as the do-minimum option. The key differences are the route (Dominion Road or Sandringham Road) and the mode (light rail or light metro) (including the option for northwards extension). The IBC options for ALR are:

- Do minimum
- Option 1b - light rail along the Dominion Road alignment
- Option 2a - light metro along the Sandringham Road alignment
- Option 3 – combination of light rail and light metro along the Sandringham Road alignment

The WoL carbon impact assessment was informed by five emission sources listed below. The key outputs of the assessment included emission reduction potential, emissions reduction per year, and emission profile over 60 years. The results are dependent on available data at the time of the assessment. The methodology, data sources, assumptions for each of the three emission assessments are documented in this report.

The seven sources of emission contribution and emission savings include:

1. Source 1 - Emissions from ALR asset construction activities.
2. Source 2 - Emissions from ALR asset operational activities.
3. Source 3 - Emissions from transport users across Auckland due to the impact of ALR.
4. Source 4 - Emission savings from reduced road construction and car parking spaces across Auckland due to the impact of ALR.
5. Source 5 - Emissions savings due to lower energy requirements of denser housing typologies along ALR corridor.

9.1 Assessment process

1. Undertook literature review of carbon assessment methodologies for metro and light rail emissions. Refer to the footnotes in the report for sources. Refer to Chapter 9.5.6 for carbon emissions from international light rail and metro projects.
2. Engagement with project design team to understand the design features and assumptions.
3. An internal peer review of the carbon methodologies developed for this carbon assessment.
4. The assessment was conducted, and the following items were documented for each of the three carbon emissions sources in Chapter 9.
   - Data log
   - Activities and factors considered
   - Summary of the assessment methodology and assumptions for each activity
   - Exclusions from the assessment at IBC stage due to data availability

9.2 Models

Three models were developed by Arup. Each model used to assess the carbon emissions from each of the three carbon sources.

- Waka Kotahi Carbon Transport User Emissions Model Version 2– used to determine emission reduction potential, conduct the ASI assessment, and conduct the WoL Profile assessment.
- Carbon Construction Model Version 1 – used to determine the emissions associated from the construction of ALR assets.
- Carbon Operations Model Version 1- used to determine the energy use and associated emissions from ALR assets.

9.3 Boundaries for each carbon source

As required by the GPS Alignment Investment Prioritisation Method, the following boundaries were defined for the carbon assessment for each of the three carbon emission sources.

Transport user emissions	Construction emissions	Operational emissions
The boundary is based on the MSM boundary, i.e. all of Auckland. Other boundaries which informed the factors assessed included: • Land use change and development capacity assumptions = 1km either side of the corridor • Station catchments = 800m walking catchment • Zone catchments for population growth around the corridor.	The legal boundary of the corridor and station buildings.	The boundary based on the emissions from the equipment used to operate the rapid transit system. This includes the rolling stock and stations buildings.

9.4 Annual operational carbon emissions

The operational carbon impact of the proposed scheme is reported in tCO2e and was assessed for a single year of operation for ease of comparison across the different options. New Zealand's electricity grid is expected to become more renewable over time, with the Climate Change Commission recommending a target of 95-98% renewable electricity by 2030. As such, it can be expected the operational emissions from ALR to be lower than what has been estimated in this chapter.

9.4.1 Data log table

Table 6 in the first column shows the factors that were identified that can influence the operational emissions for light rail ad light metro. It shows which of these datasets were available for the assessment and the associated source. Due to a lack of information around station energy requirements, assessment of the operational carbon emissions from the stations (lighting, ventilation etc.) was not included. Annual operational carbon emissions were assessed for the operation of all options.

Table 6: Data log for assessing operational emissions

Material impact	Dataset	Available for IBC MCA assessment?	Source
High	Track distance km	Yes	ALR briefing presentation by Andrew Hale on 2/08/21
High	Gradient of alignment	Yes	ALR briefing presentation by Tilo Franz on 2/08/21
High	New Zealand electric grid carbon footprint	Yes	Measuring emissions: a guide for organisations (MfE)[12]
High	Energy requirements for rolling stock	No	Use of reference estimates of energy consumption for typical light rail and metro schemes[13]
High	Frequency and capacity	Yes	ALR briefing presentation by Theunis Van Schalkwyk on 2/08/21
Medium	Station and depot operational requirements	No	No source available. Recommended to be used for DBC assessment.
Low	Trackside ventilation	No	No source available. Recommended to be used for DBC assessment.
Low	Lighting	No	No source available. Recommended to be used for DBC assessment.
Low	Asset maintenance	No	No source available. Recommended to be used for DBC assessment.
High	Regenerative braking	No	No source available. Recommended to be used for DBC assessment.

9.4.2 Calculation methods & assumptions

Table 7 details the methodology and assumptions made for assessing annual operational emissions.

Table 7: Methodology and assumptions made for assessing operational emissions

Methodology	Assumptions
Calculate distance travelled along the light rail/metro system for a given year	Services operate at 4-minute intervals for light rail and 3-minute intervals for light metro during peak hours and 8-minute intervals during non-peak hours for both.
Use typical values of energy consumption per km for light rail/metro to determine approx. values of energy consumption for the system	As gradients across the different options do not vary significantly from each other, it was assumed that gradient would not affect operational emissions greatly. This assessment did not include the use of regenerative braking which will substantially lower operational emissions.
Use emissions factors to calculate carbon emissions for each option	Emissions from the electricity grid will remain at 2018 level by the time of completion for light rail and metro. In reality, it is likely that New Zealand's electricity grid will become increasingly renewable, and the emissions factor will reduce. There is even a possibility that the electricity grid

[12] MfE (2020). Measuring emissions: a guide for organisations. Available from: https://environment.govt.nz/assets/Publications/Files/Measuring-Emissions-Detailed-Guide-2020.pdf

[13] ETSAP (2011). Public transport. Available from: https://iea-etsap.org/E-TechDS/PDF/T10_Public_Transport_v3_final_gs06062011.pdf

	will be completely renewable and there will be no emissions resulting from the operation of the system.

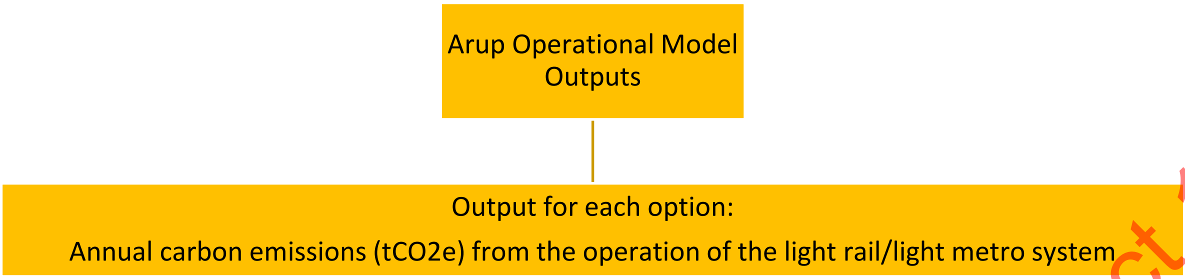

Figure 9-1: Operational carbon emissions model outputs

9.4.3 Exclusions:

- Regenerative braking – this has the potential to substantially lower operational emissions
- The effect of gradient on operational emissions
- Energy requirements of the rolling stock – rolling stock specifications have yet to be determined
- Station and depot operational emissions (from lighting, asset maintenance, trackside ventilation, signalling, communications)

9.4.4 Results

Operational emissions are higher for options that travel more service kilometres, such as the Sandringham road options. Light metro options require more electricity as they have higher frequencies and carry more passengers. The hybrid and light rail on dominion road options performs the best operationally as it has carried fewer passengers and has a lower frequency than light metro options. See Table 8 for detailed results.

Table 8: Results of the annual operational emissions for all five IBC options

Operational emissions	Option 1b	Option 2a	Option 3
Track distance (km)	24.0	24.0	24.5
Services per year	76,650	83,950	76,650
Maximum capacity (seats)	128	150	128
Energy consumption (kWh/seat-km)	0.08	0.07	
Energy consumption (MWh)	18,838	21,155	16,826
Emissions factor (tCO2e/MWh)	0.101		
GHG emissions (tCO2e)	1,903	2,137	1,699

GHG emissions (tCO2e)	1,100 – 2,700	1,300 – 3,000	1,000 – 2,400
MCA score	**-1**	**-2**	**-1**

9.5 Construction carbon emissions

Construction carbon represents the carbon emissions associated with construction operations such as constructing the light rail infrastructure, as well as the embedded carbon within the bulk construction materials. The assessment of embedded carbon has included the carbon impact from the construction of each of the 5 options. The aim was to understand the estimated difference in carbon emissions across the 5 options.

The approach for the assessment is summarised below:

- Identification of embedded carbon from a collection of construction activities
- Collation of data and associated emissions factors
- Estimation of the relative difference in carbon impact

9.5.1 Data log table

Table 9 details the construction factors assessed and the sources of information used for the assessment. Information concerning earthworks and utilities was only partially available, and information around new roading layouts and the transportation of materials was not available.

Table 9: Construction activities assessed and source of information

Most material impact	Dataset	Available for IBC MCA assessment?	Source/date/drawing name/version
High	Rail tracks – at grade, trenched, tunnelled	Yes	Taken from drawings sets issued 02/08/2021: AUCKLAND LIGHT RAIL - DOMINIUM-LIGHT RAIL-OPTION 1B-DRAWING INDEX version 1 AUCKLAND LIGHT RAIL - DOMINIUM-LIGHT METRO-OPTION 2B-DRAWING INDEX version 1 AUCKLAND LIGHT RAIL - SANDRINGHAM-LIGHT METRO-OPTION 2A-DRAWING INDEX version 1 AUCKLAND LIGHT RAIL - SANDRINGHAM-LIGHT RAIL-OPTION 1A-DRAWING INDEX version 1 AUCKLAND LIGHT RAIL - SANDRINGHAM-HYRBID-OPTION 3-DRAWING INDEX version 1
Medium	Utilities	Partial	ALR briefing presentation by Alastair Stewart on 2/08/21

High	Earthworks	Partial	ALR briefing presentation by Alastair Stewart on 2/08/21
Medium	Pavement materials for new roads	No	No source available. Recommended to be used for DBC assessment.
Low	Plant and equipment use	Partial	Drawings (as above) Assumptions around operations of hours for TBM use and specifications were made based on Melbourne metro[14]
High	Transportation of materials	No	No source available. Recommended to be used for DBC assessment.
High	Bridges	Yes	Drawings (as above)
Medium	Retaining walls	No	No source available. Recommended to be used for DBC assessment.
Medium	Manufacture of rolling stock	No	No source available. Recommended to be used for DBC assessment.
Medium	Depot	No	No source available. Recommended to be used for DBC assessment.
Low	Culverts	No	No source available. Recommended to be used for DBC assessment.
Low	Fencing	No	No source available. Recommended to be used for DBC assessment.
High	Stations	Partial	Drawings (as above) Project references were used to develop estimates of the carbon emissions from the construction of stations. Reference cases include a confidential project[15], Shenzhen, Wuhan, Shenyang[16], Dadongmen station[17], Melbourne Metro[18], and the Sheppard line[19].

9.5.2 Calculation methods & assumptions

The following table sets out the assumptions made for each of the construction activities assessed.

[14] MMRA (2016) Greenhouse gas impact assessment. Available from: https://metrotunnel.vic.gov.au/__data/assets/pdf_file/0016/51091/MMRP-Technical-Appendix-V-Greenhouse-Gas.pdf

[15] Taken from Arup's internal carbon insights platform for infrastructure

[16] Mao et al. (2021). *Global urban subway development, construction material stocks, and embodied carbon emissions.* Available from: https://www.nature.com/articles/s41599-021-00757-2

[17] Kaewunruen et al. (2020). *Digital twin aided sustainability and vulnerability audit for subway stations.* Available from: https://ideas.repec.org/a/gam/jsusta/v12y2020i19p7873-d418024.html

[18] MMRA (2018). *Greenhouse gas.* Available from: https://metrotunnel.vic.gov.au/__data/assets/pdf_file/0013/51052/MMRP_Chapter-22_Greenhouse.pdf

[191919] Saxe et al. (2017). *The net greenhouse gas impact of the Sheppard Subway Line.* Available from: https://www.semanticscholar.org/paper/The-net-greenhouse-gas-impact-of-the-Sheppard-Line-Saxe-Miller/a69f0acc3e2edfd55eaf59922befffcd7e37927f

Table 10: Assumptions made for assessing construction activities

Activity	Assumptions
Earthworks	It is assumed that the spoil is dominated by tunnel spoil or spoil produced by trenching, tunnelling, relocating utilities, and constructing the underground stations. It does not quantify the level of emissions that are associated with earthworks as the volume of earthworks have yet to be quantified.
Rail tracks – at grade, trenching, tunnelling	Standard multipliers for steel and concrete requirements per unit length of rail, rail driveway, and tunnels, were derived from previous studies. Type of rail track was assumed to be a slab track. It was assumed there are 2 rails per track. Elements included for assessment: rail section, grouting, concrete, lining/protection layers, subgrade, and ballast.
Bridges	Standard multipliers for steel and concrete requirements per unit bridge were derived from previous studies. Elements included for assessment: concrete, steel, asphalt, protection layers, piping. It was assumed that 25kg reinforced steel is used per m3 of concrete for tunnels. Bridge cross sections were approximated from typical bridge structures developed for this project, and column heights were estimated from the alignment.
Stations	It is assumed that the carbon emissions from constructing stations around the world will be similar to the emissions from constructing emissions in this project. There is a large amount of uncertainty in the estimates from the calculation of carbon emissions for stations, as emissions factors, station sizes, and material requirements will all differ.
TBM	TBM specifications were assumed to be similar to the TBM used for the construction of Melbourne Metro. It was assumed power consumption of the TBM would be 2500 kwh with a load factor of 50%, the TBM would travel 10 m/day and the TBM would be operating 20 hours a day.

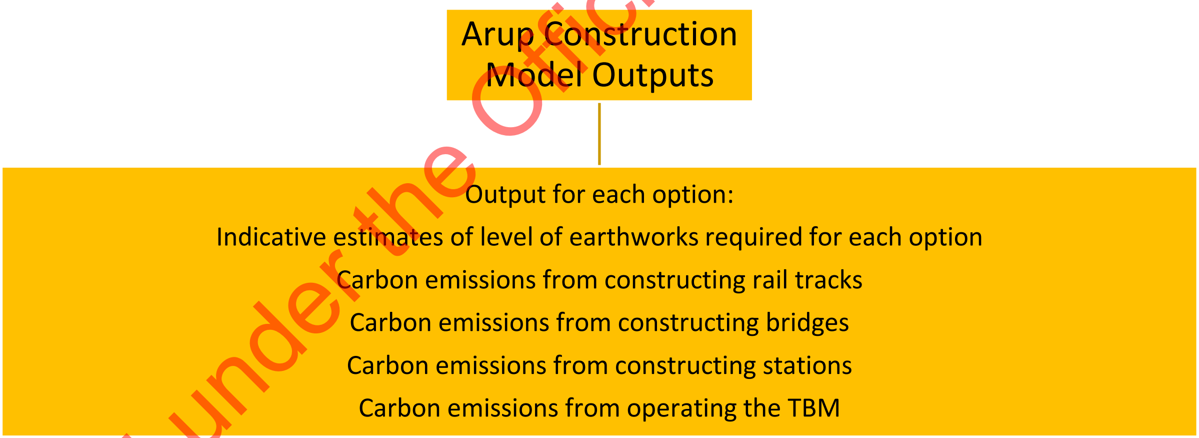

Figure 9-2: Construction carbon emissions model output

The following paragraphs present an in-depth summary of the methodology for each of the assets constructed.

Earthworks emissions

Earthwork carbon emissions typically result from the use of plant equipment and the transport of spoil to disposal sites. As the volume of earthworks required has yet to be quantified, assessment of earthworks have been to simply evaluate the extent of earthwork intensive activity (construction of underground stations, trenching, and tunneling) for each of the options. Each option was assessed with a low, medium, or high rating corresponding to the level of required earthworks.

Rail tracks emissions

The main constituents of a slab track are rail section (steel), grouting (grout), concrete slab (precast reinforced concrete); hydraulically bound layer (aggregate and binder); protection layer (aggregate and binder); subgrade layer (sand); and ballast (crushed rock/gravel).

The following tables sets out the carbon profiles for a typical slab track for an at-grade section (Table 11), a tunnel section (Table 12), and a trenched section of track (Table 13). It contains detail on material types, percentage of asset mass, and GHG emissions per meter of track.[20, 21]

Slab track – at grade emissions

Table 11: Emissions from constructing at-grade rail tracks

Major element	Material	Density (kg/m^3)	Mass (kg/m track)	% of Asset (mass)	GHG emissions factor (kgCO_2e/kg)	GHG emissions (kgCO_2e/m track)
Rail Section	steel	7,800	74	1	3.97	293.78
Grouting (including shear keys)	grout	1,860	459	4	0.74	339.68
Concrete slab in open section	precast reinforced concrete (RC)	2,200	1,364	11	0.23	313.72
Hydraulically bound layer (cast in-situ)	aggregate and binder	2,240	2,172.8	18	0.01	11.3
Protection layer	aggregate and binder	2,240	2,172.8	18	0.01	11.3
Subgrade layer	sand	2,240	2,172.8	18	0.01	11.3
Ballast	crushed rock / gravel	2,240	3,920	32	0.01	20.38
TOTAL						**1,001.46**

Slab track – bored tunnel section emissions

Table 12: Emissions from constructing tunnels

Major element	Material	Density (kg/m^3)	Mass (kg/m track)	% of Asset (mass)	GHG emissions factor (kgCO_2e/kg)	GHG emissions (kgCO_2e/m track)

[20] Taken from Arup's internal carbon insights platform for infrastructure
[21] Emissions factors for steel and concrete were taken from BRANZ CO2nstruct. Steel values were based off "Steel, bar (Pacific steel" and 30MPa concrete with 50 kg/m3 steel reinforcing where relevant.

Rail section	steel	7,800	74	1	3.97	293.78
Grouting (including shear keys)	grout	1,860	459	3	0.74	339.68
Concrete slab in bored tunnel	in-situ reinforced concrete (RC)	2,300	2,544	19	0.21	534.24
Hydraulically bound layer (cast in-situ)	aggregate and binder	2,240	2,172.8	16	0.01	11.3
Protection layer	aggregate and binder	2,240	2,172.8	16	0.01	11.3
Subgrade layer	sand	2,240	2,172.8	16	0.01	11.3
TOTAL						**1,201.6**

Slab track – trenched section emissions

Table 13: Emissions from constructing trenched sections of rail track

Major element	**Material**	**Density (kg/m³)**	**Mass (kg/m track)**	**% of Asset (mass)**	**GHG emissions factor (kgCO₂e/kg)**	**GHG emissions (kgCO₂e/m track)**
Rail section	steel	7,800	74	0	3.97	293.78
Grouting (including shear keys)	grout	1,860	459	3	0.74	339.68
Concrete slab in cut and cover tunnel	in-situ reinforced concrete (RC)	2,300	5016	31	0.21	1,053.36
Hydraulically bound layer (cast in-situ)	aggregate and binder	2,240	2,172.8	14	0.01	11.3
Protection layer	aggregate and binder	2,240	2,172.8	14	0.01	11.3
Subgrade layer	sand	2,240	2,172.8	14	0.01	11.3
Ballast	crushed rock / gravel	2,240	3,920	25	0.01	20.38
TOTAL						**1,741.1**

The largest sources of carbon emissions come from the steel and concrete for each of the track types. Trenched sections of rail are far more carbon intensive than at grade rail section and tunneled sections.

Bridge emissions

The key constituents and elements of a typical bridge include the following: reinforced concrete (piers, deck slab, abutment walls, piles, pile caps, beams), steel (beams and bolts), asphalt, protection layers, and piping.

The following table sets out the carbon profiles for a typical bridge. It contains detail on material types, percentage of asset mass, and GHG emissions per meter of track.[22, 23]

Table 14: Emissions from constructing a bridge

Material	Location	Worst-case % of bridge volume	Density	Normalised mass (kg/m3 of asset)	GHG emission factor (kgCO2e/kg)	Normalised GHG emissions (kgCO2e/m3 of asset)
Reinforced concrete	Pier, deck slab, abutment wall, piles, pile caps, transition slab, beams, parapet	92%	2,300	2,116	0.23	486.68
Concrete (non-reinforced)	Kerbs	<1%	2,200	22	0.13	2.86
Steel	Beams	2%	7,800	156	3.97	619.32
Steel	Bolts	0.8	7,800	11	3.97	43.67
Steel	Expansion joints (1%)	1%	7,800	78	3.97	309.66
Teflon-coated steel	Pot bearings	0.02	7,800	1.6	3.97	6.352
Elastomer	Joints and bearings	0.10%	1,500	2	2.85	5.7
Hot rolled asphalt	Carriageways	<1%	1,700	17	0.066	1.122
Waterproof coating	Deck slab	0.10%	1,380	1	1.57	1.57

[22] Taken from Arup's internal carbon insights platform for infrastructure
[23] Emissions factors for steel and concrete were taken from BRANZ CO2nstruct. Steel values were based off "Steel, bar (Pacific steel" and 30MPa concrete with 50 kg/m3 steel reinforcing where relevant.

Drainage stone	Drainage	1%	2,240	22	0.005	0.11
Concrete (non-reinforced)	Drainage	2%	2,200	44	0.13	5.72
PVC/PE	Drainage	0.10%	1,380	1	3.1	3.1
Total						**1,485.864**

Where not provided, dimensions were estimated from other drawings or approximated. Some bridge designs were not provided, so the dimensions were estimated to be similar to type C bridges (the bridge with the largest volume). There will likely be significant variance in these estimates once designs have been completed, as most measurements were not provided, and bridges have yet to be fully designed.

Station emissions

Carbon emissions from the construction of stations primarily come from the quantity of materials required to build the station (primarily steel and concrete). As the quantity of materials have yet to be determined, estimates of the carbon emissions from the construction of stations are high level and were developed relative to the other options. This assessment only looked at the embodied materials used for constructing the stations, not the volume of earthworks required for the construction of underground stations so as to not double count. The volumes concrete and glass required to build light rail stations were estimated from light rail station drawings (Table 15). The emissions from constructing underground stations were based off the emissions produced from constructing metro and subway stations from around the world including Melbourne Metro[24], Dadongmen station (subway station in China)[25], Sheppard subway line (Canada)[26], and subway stations in Shenzhen, Wuhan, and Shenyang[27] (Table 16). As the size of the stations are yet to be determined, it is difficult to approximate what the relative carbon impact will be. The emissions from constructing above ground stations were based off the emissions produced from constructing the stations from a confidential rail project (Table 16).[28]

[24] MMRA (2018). *Greenhouse gas.* Available from: https://metrotunnel.vic.gov.au/__data/assets/pdf_file/0013/51052/MMRP_Chapter-22_Greenhouse.pdf

[25] Kaewunruen et al. (2020). *Digital twin aided sustainability and vulnerability audit for subway stations.* Available from: https://ideas.repec.org/a/gam/jsusta/v12y2020i19p7873-d418024.html

[26] Saxe et al. (2017). *The net greenhouse gas impact of the Sheppard Subway Line.* Available from: https://www.semanticscholar.org/paper/The-net-greenhouse-gas-impact-of-the-Sheppard-Line-Saxe-Miller/a69f0acc3e2edfd55eaf59922befffcd7e37927f

[27] Mao et al. (2021). *Global urban subway development, construction material stocks, and embodied carbon emissions.* Available from: https://www.nature.com/articles/s41599-021-00757-2

[28] Taken from Arup's internal carbon insights platform for infrastructure

Table 15: Emissions from constructing a light rail station

Major element	Material	Density (kg/m³)	GHG emissions factor ($kgCO_2e/kg$)	GHG emissions ($kgCO_2e/m3$)	Volume per station	GHG emissions (tCO_2e/station)
Light rail station						
Roof	Glass	2,500	1.18	2,950	4.212	12.4254
Concrete slab (cast in-situ)	Concrete	2,300	0.21	483	308	148.764
Total						**161.1894**

Table 16: Reference rail station construction emissions

Station	Emissions per station (tCO2e)	Size
Underground stations		
Melbourne Metro	59,600	Large
Dadongmen Station	16,279	Small
Sheppard line	60,258	Large
Shenzhen, Wuhan, Shenyang	34,515	Medium
Above ground stations		
Confidential rail project	4,636	

TBM electricity

TBM specifications were assumed to be similar to the TBM used for the construction of Melbourne Metro. It was assumed power consumption of the TBM would be 2500 kwh with a load factor of 50%, the TBM would travel 10 m/day and the TBM would be operating 20 hours a day. Emissions factors was taken from the Ministry for the Environment. A factor of 0.101 kgCO2e/kwh was used from table 9 of the guide for measuring emissions from the electric grid.[29] It should be noted that two tunnels must be constructed for metro schemes.

9.5.3 Exclusions for construction emissions

- Emissions from the transportation of material/earthworks
- Emissions from constructing new roads
- Emissions from manufacturing rolling stock
- Emissions from constructing retaining walls
- Emissions from constructing culverts and fencing
- Emissions from the use of plant equipment

[29] MfE (2020). *Measuring emissions: a guide for organisations*.

9.5.4 Results

Earthworks

The options were compared to each other based on the relative difference in intensity of required earthworks from constructing the alignment and constructing the underground stations. Light metro options require significantly more earthworks than light rail options, due to tunneling, trenching and the need for underground stations. Light rail down Sandringham road requires significantly more earthworks than Dominion road options due to the need to relocate a number of utilities.

Table 17: Assessment of the level of earthworks required

	Option 1b	Option 2a	Option 3
Rail track - At grade (%)	86%	32%	48%
Rail track - Tunnelled (%)	0%	48%	39%
Rail track - Trenched (%)	14%	20%	12%
Underground stations	1	12	10
Utilities	High	Medium	Medium
Score	**Low**	**High**	**High**

Rail tracks

Trenching is the most emissions intensive activity, so options that require less trenching perform better than those that require more. Options 1a and 1b produce the lowest level of emissions for constructing the rail tracks.

Table 18: Emissions from constructing rail tracks

		Emissions factor (kgCO2e/m track)	Option 1b	Option 2a	Option 3
At grade	Track length (km)		20.7	7.6	11.8
	GHG emissions (kgCO2e)	1,001	20,700	7,611	11,817
Tunnelled	Track length (km)		0.0	11.6	9.7
	GHG emissions (kgCO2e)	1,202	0	13,975	11,619
Trenched	Track length (km)		3.3	4.8	3.0
	GHG emissions (kgCO2e)	1,741	5,798	8,305	5,276
Total	**GHG emissions (tCO2e)**		**26,498**	**29,891**	**28,712**

Bridge emissions

Light metro and the hybrid options performed better in this assessment as much of the alignment is tunneled, so fewer bridges/viaducts are required. Emissions from constructing bridges for light rail options are fairly significant.

Table 19: Emissions from constructing bridges

	Option 1b	Option 2a	Option 3
Bridge length (m)	3.06	2.32	2.9
Bridge volume (m3)	57,778	34,480	53,592
GHG emissions (kgCO2e/kg of asset)			1486
GHG emissions (tCO2e)	**85,851**	**51,233**	**79,630**

Stations

The options were compared with each other based on the relative size and number of stations. Overall, the light rail options would produce lower amount of carbon emissions due to smaller station sizes that are easily constructable above ground.

Table 20: Estimates of the emissions from constructing new stations

	Option 1b	Option 2a	Option 3
Underground stations - small	1	1	0
Emissions factor (tCO2e/station)		16,279	
Underground stations - medium	0	8	5
Emissions factor (tCO2e/station)		34,515	
Underground stations - large	0	3	3
Emissions factor (tCO2e/station)		59,600	
Surface stations	21	5	10
Emissions factor (tCO2e/station)	161	4,636	161
Emissions (tCO2e)	**19,664**	**494,381**	**352,987**

TBM electricity

Using factors derived from studies on the typical energy use of TBM's and emissions factors for electricity consumption, an estimate for the carbon emissions for the options was calculated. Light metro options were the only options that required tunneling, so they performed worse than light rail options.

Table 21: Emissions from operating the TBM

	Option 1b	Option 2a	Option 3
Tunnelling length (km)	0	11.63	9.67
Energy consumption MWh	0	58,150	48,350
Emissions factor (tCO2e/MWh)			0.101

GHG emissions (tCO2e)	**0**	**5,873**	**4,883**

9.5.5 Results summary for construction

Light metro options create more construction emissions than light rail options. The construction of underground stations is the primary source of carbon emissions for light metro options. The construction of bridges is the primary source of carbon emissions for light rail options. Construction of a light rail and metro down Sandringham creates more carbon emissions than one down Dominion road due to the longer track distance and the greater number of stations. It should be noted that the estimates for light metro stations contain the largest amount of uncertainty, due to estimates being based off reference projects. Therefore, the estimates have been presented with an uncertainty factor of +/- 40%. Once the bill of quantities for constructing the underground stations have been completed, it is likely these values will change.

Note: Total emissions are a combination of emissions from the rail tracks, bridges, stations and TBM. A range has been provided to account for uncertainty on the specific assets that will be evaluated at future stages (DBC).

Table 22: Carbon emissions from construction

Asset (tCO2e)	Option 1b		Option 2a		Option 3	
Rail track	26,498		29,891		28,712	
Bridges	85,851		51,233		79,630	
Stations	19,664		494,381		352,987	
TBM electricity	0		5,873		4,883	
Total GHG emissions	132,013		581,378		466,213	
	Low	High	Low	High	Low	High
Total GHG emission (lower to upper range)	79,000	185,000	349,000	814,000	280,000	653,000
Earthworks	Low		High		High	
MCA Score	**-1**		**-3**		**-2**	
	Option 1b produces a lower amount of carbon emissions than light metro options, mainly because of the smaller station sizes.		Option 2a produces the highest amount of carbon emissions, mainly because of the higher number of		Option 3 produces a higher amount of carbon emissions than light rail options, mainly because of the higher number of stations that	

	The majority of construction emissions come from the large number of bridges required for the option.	stations that are located underground. The construction of underground stations are emissions intensive.	are located underground. However, emissions are lower than light metro options because there are fewer underground stations and smaller stations past Mt Roskill.

9.5.6 Benchmarking construction emissions

A literature review was conducted to assess the construction emissions from similar light rail and metro schemes from around the world.[30, 31] An approximate length of 25 km is used for light rail schemes and 23 km for light metro schemes for ease of comparison. Adjusted emissions from the Tokyo light rail scheme are similar to the estimates of light rail schemes in Auckland. Adjusted emissions for Crossrail and Sheppard Subway are similar to the lower and middle estimates for light metro schemes.

Table 23: Light rail and metro construction emissions benchmarked with similar projects

Transport mode	Variable	Reference project emissions	Adjusted emissions for Auckland context (tCO2e)	Project
Light rail	Construction emissions	5,000 tCO2/km	142,500	Tokyo light rail - 10% of the line was tunnelled
Metro	Construction emissions	12,712 tCO2/km	308,266	Crossrail
Subway	Construction emissions	30,445 tCO2/km	738,291	Sheppard subway line
Metro	Construction emissions	7,1333 tCO2/km	1,640,667	Melbourne Metro
Metro	Construction emissions	39,455 tCO2/km	907,459	Sydney Metro
Rail	Construction emissions	55,391 tCO2/km	1,274,000	CRL

9.6 Transport system (enabled) carbon emissions

The transport system carbon emissions represent the carbon emissions associated from the use of the transport system as result of the ALR options. There is no established methodology for undertaking a user carbon emissions assessment and as a result a variety of assumptions have been made. The key aim was to understand the contributing factors that's can help reduce emissions. These ranged from policy, regulatory, transport design factors. In addition to this, the modelling outputs from MSM were used to understand the Co2 emissions, as well as the mode shift from cars to PT/active modes across the 5 options

[30] Chester and Horvath (2009). *Environmental assessment of passenger transport should include infrastructure and supply chains*
[31] Olugbenga et al. (2019). *Embodied emissions in rail infrastructure: a critical literature review*

and do min. Figure 9-3 shows the sources for data used to determine the potential impact on carbon from the transport system.

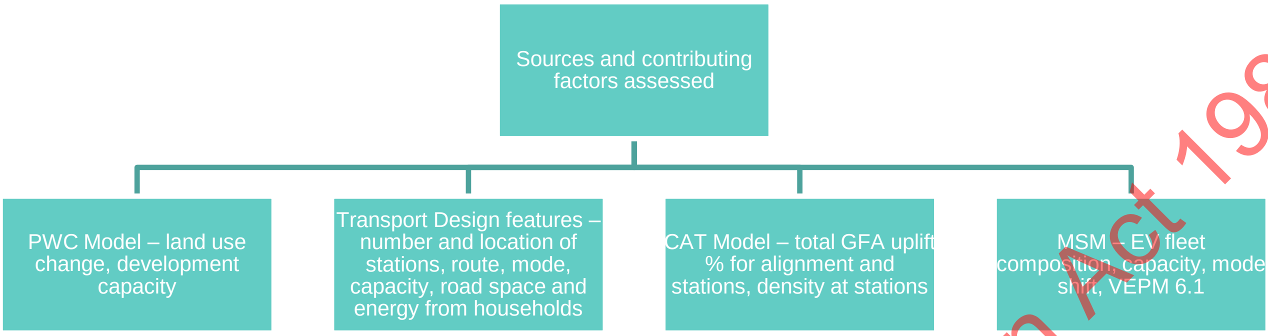

Figure 9-3: Inputs and sources for the Carbon Transport User Emissions Model Version 2

9.6.1 Data log table

Table 24 shows the datasets used for the transport system carbon assessment, it identifies the datasets which have the most impact on the MCA scores, the availability status and source.

Table 24 Transport system emissions assessed and sources of information:

Most material impact	Dataset	Available for IBC MCA assessment?	Source/date/drawing name/document name
Medium	GFA uplift % within 800m catchment of the stations	Yes	CAT model
Medium	GFA for residential and commercial	Yes	CAT model
High	Capacity per hour for all options	Yes	MCA briefing pack 2 Aug 2021
Medium	No of stations for all options	Yes	MCA briefing pack 2 Aug 2021
Medium	Journey time for all options	Yes	MCA briefing pack 2 Aug 2021
High	Number of general traffic lanes removed	Partially	MCA briefing pack 2 Aug 2021
Medium	No. Of bus stops and urban interchanges	Yes	MCA briefing pack 2 Aug 2021
Medium	Cycle access to stations, new or retained cycle lanes/paths	Partially	MCA briefing pack 2 Aug 2021
High	Mode shift from car	Yes	MSM
High	Co2 emissions/yr	Yes	MSM
High	TOD features at each station within 800m	No	No source available. Recommended to be

			used for DBC assessment.

9.6.2 Activities assessed for transport system carbon emissions

1. Emission reduction potential based on factors that would influence mode-shift, or influence uptake in zero emission mobility
2. MSM carbon emissions
3. MSM mode shift from car

Table 25 shows the factors assessed for activity 1 to determine the emission reduction potential of the options. The table shows the metrics measures based on the available data and shows how it aligns to the MCA criteria. While there are a number of other factors that can help reduce transport emissions, the scores of these factors where the same across all the options and therefore did not help differentiate between the options. For this reason, they were excluded from this assessment and not shown in Table 25.

Table 25: Transport activities assessed and associated drivers of carbon emissions for activity

Factors for activity 1	**The most important factors that differentiated the options were:**	**MCA criteria**
Transit oriented development (TOD) Zoning - mixed use (residential and zoning) vs single use complemented by higher population density	• Increased development density via GFA uplift within the 800m catchment,	Supports high density low carbon urban uplift
Urban planning	• Equal split in mixed use zoning via GFA uplift for residential and employment zones, removal of general traffic road capacity.	Supports high density low carbon urban uplift Station proximity and accessibility to users (residential, town centres, employment, medical, education)
Light rail, metro rail and commuter rail systems	• An attractive PT via light rail/light metro would promote mode choice to PT and away from the car based on the capacity, travel time, number of stations provided.	Ability to effect mode shift and travel patterns (i.e. attract patronage, reduced peaks)
Removing road capacity for passenger travel	• Fewer road capacity for general traffic means PT and active modes become more attractive options.	Ability to effect mode shift and travel patterns (i.e. attract patronage, reduced peaks)
Bus rapid transit	• Attractive bus rapid transit to support connection to the light rail/light rail system (number of stations and urban interchanges along the proposed alignment) would promote interconnectivity to other transit and active modes.	Interconnectivity to other transit and/or active modes

Bicycle infrastructure	• Provision of improved cycle infrastructure and connection to existing cycle network promotes the use of low emission modes.	Interconnectivity to other transit and/or active modes

9.6.3 Calculation methods & assumptions

Table 26 outlines the methodology to assess the three activities for transport system carbon emissions. It also captures the key assumptions made and the reasoning behind how the activities were scored.

Table 26: Methodology and assumptions made for assessing transport system emissions

Methodology for each activity	Assumptions	Reasoning based on research
Activity 1 • Identified the list of factors/interventions (policy, regulatory, design features, market driven) that can help reduce emissions from transport for the Arup GHG Tool • Identified which ones were out of scope at the IBC stage • Narrowed down the factors based on the data available at this stage and identified which would have the most material impacts. The GHG rating was assigned to each of the factors based on the matrix shown below. • Translated the GHG rating of emission reduction potential to the MCA score. See Table 27. **Activity 2** We used the 2018, 2031 and 2051 carbon emissions from the MSM model and assigned an MCA score. **Activity 3** We used the 2018, 2031 and 2051 mode-shift % from the MSM model and assigned an MCA score. Averaged the scores for all 3 activities to get the MCA score for the transport system emissions criteria	Each option includes do min plus the specific design features for the options modelled on MSM.	The justifications for the GHG rating were based on literature review. These were used to inform the impact the interventions/factors could have on emissions from the transport system.

Table 27 captures the GHG rating used to assess activity 1.

Table 27: GHG Rating Matrix

Climate assessment	**Category**
High to Medium emissions reduction potential	5,6,7
Medium to Low emissions reduction potential	2,3,4
Low to Neutral emissions reduction potential	1
Potential to increase emissions	0

Table 28 captures the assumptions and metrics assessed to determine the GHG rating.

Table 28: Assumptions and metrics used to assess activity 1 and get a GHG rating

Sub-Categories	MCA criteria	Do min (comparison across options not across scenario years)	Option 1b-LR Dominion	Option 2a- LM Sandringham	Option 3- LR LM hybrid Sandringham
Transit oriented development (TOD) Zoning - mixed use (residential and zoning) vs single use complemented by higher population density	Supports high density low carbon urban uplift		Sandringham has a more equal split in residential and commercial GFA (using the AUP GFA) than the dominion rd. Options within an 800m radius of the stations. Densities are relatively similar across all options.	Sandringham have a more equal split in residential and commercial GFA (using the AUP GFA) than the dominion rd options within an 800m radius of the stations. Densities are relatively similar across all options.	Sandringham have a more equal split in residential and commercial GFA (using the AUP GFA) than the dominion rd. Options within an 800m radius of the stations. Densities are relatively similar across all options.
Urban planning codes and practices	Supports high density low carbon urban uplift - Station proximity and accessibility to users (residential, town		Is there Higher development density and mixed-use zoning? = 9.5%GFA uplift due to the option. Are the employment and residential centres closer to each other due land use changes or new developments? = less increases in residents,	Is there Higher development density and mixed-use zoning? = 11.5% GFA uplift due to the option. Are the employment and residential centres closer to each other due land use changes or new developments? = higher increases in residents,	Is there Higher development density and mixed-use zoning? = 11.3% GFA uplift due to the option. Are the employment and residential centres closer to each other due land use changes or new developments? = higher increases in residents,

	centres, employment, medical, education)		employees, and households along the corridor than LM options	employees, and households along the corridor than LR options	employees, and households along the corridor than LR options
Light rail, metro rail and commuter rail systems	-Ability to effect mode shift and travel patterns (i.e. attract patronage, reduced peaks) *	LR/LM access points = 0 stations LR/LM Capacity = 0	LR Access points = 22 stops, which means shorter distances than LM, and it has a larger urban area catchment. Headway=4min peak. LR Capacity =6300 people per hour per direction. Journey time = 57 min.	LM Access points = 17 stations, which means longer distances than LR, and it has a smaller urban area catchment. LM Capacity = 11600 people per hour per direction. Headway=3min peak. Journey time = 36min.	LR/LM access points = 10 stops, 8 stations. Good catchment in suburbs and adequate catchment in city centre. LR/LM Capacity = 8400 people per hour per direction. Headway=3min peak Journey time = 44min
Removing road capacity for passenger travel	-Ability to effect mode shift and travel patterns (i.e. attract patronage, reduced peaks) *		LR options are on the existing road corridor, it is assumed that existing lanes for general traffic will be removed to make room for LR.	LM options are not on the road corridor, so it is assumed that existing lanes for general traffic will remain.	Some of the existing road corridor will have general traffic lanes removed for LR, however options 1a and 1b would result in more general traffic lanes being removed.
Bus rapid transit	Interconnectivity to other transit and/or active modes*	Number of stations along the proposed LR/LM alignment are accessible by bus = 0 Journey time = na	Number of stations along the proposed LR/LM alignment are accessible by bus = 7 on street stops (Isthmus section) 3 urban interchanges = Mt	Number of stations along the proposed LR/LM alignment are accessible by bus = 4 on street stops (Isthmus section)	Number of stations along the proposed LR/LM alignment are accessible by bus = 4 on street stops (Isthmus section) 3 urban interchanges =

			Roskill, Onehunga, and Mangere Town centre	3 urban interchanges = Wesley, Onehunga, and Mangere town centre	Wesley, Onehunga, and Mangere town centre
Bicycle infrastructure, networks, and support programmes	Interconnectivity to other transit and/or active modes*	Will the existing cycle or shared lanes/paths remain? = yes, shared lane on Queen st will remain, and shared path in airport to remain. Existing cycle quiet routes adjacent dominion and the shared paths along approx. to remain Are there new proposed cycle lanes/paths or shared paths?= no Accessibility to stations - more stops to access at surface level, more touch points along the corridor, more active mode improvements in the city centre.	City centre - Aligns with existing A2E and cycle network planning. There is also currently shared lanes on Queen st, these would give access to 3 stations along this section of the corridor. Will the existing shared lanes on Queen st remain? = yes, and shared path in airport to remain. Are there new proposed cycle lanes/paths or shared paths? = yes, new shared path bridge across Central motorway junction after k rd station. new walking and cycle connections at dominion rd junction. Accessibility - more stops to access at surface level, more touch points along the corridor, more active	City centre - active mode connection to stations Existing cycle quiet routes adjacent dominion and the shared paths along approx. half of the SH20 part of the alignment give cycle access to 9/17 of the proposed stations. Will these existing cycle routes remain? = yes, and shared path in airport to remain Are there new proposed cycle lanes/paths or shared paths?= new walking and cycle connections at dominion rd. junction Accessibility - less stations, longer distance between access, underground access is an inconvenient factor, specific focuses around stations for WC	Existing cycle quiet routes adjacent dominion and the shared paths along approx. half of the SH20 part of the alignment give cycle access to 9/18 of the proposed stations. Will these existing cycle routes remain? = yes, queen st shared lane, and shared path in airport to remain Are there new proposed cycle lanes/paths or shared paths? = new walking and cycle connections at dominion rd. junction.

			mode improvements in the city centre.	provision, station locations are different to LR options	

9.6.4 Results

Table 29 shows the results of the 3 activities accessed for do min and all 5 options. It also shows the MCA scores for each activity.

Table 29: Results of transport system carbon emissions assessment

		Do min	Option 1b-LR Dominion	Option 2a- LM Sandringham	Option 3- LR LM hybrid Sandringham
Transport System emissions	GHG average rating	1.5	4.7	4.2	4.5
	Mode shift % from do min (+ means a reduction of car mode share from do min option)		+5.0%	+6.5%	+6.3%
	Emissions from MSM Co@ tCO2e/year	1,706,000	1,684,000	1,677,000	1,678,000
	MCA score	**-2**	**1**	**3**	**2**
	1-2 sentences of reasoning for user emission score	The do min score is significantly worse than all other options.	Option 1b provides less capacity/hour than the light metro and hybrid options. It has more stations along the proposed alignment compared to the metro and hybrid options. The option scored better than the hybrid and light metro options	Option 2a performed better than light rail options in terms of supporting high density urban development and has more capacity/hour to encourage mode shift. It is likely to provide more general traffic lanes than the	Option 3 performs better than light rail options but slightly worse than light metro options in terms of supporting urban density uplift. The key advantage of option 3 over options 2a is its ability to remove space from road

			for cycle infrastructure provision. The carbon emissions from the MSM modelling show carbon emissions from transport across Auckland producing 1,684,000 tCO2e/year, with option 1b with the highest carbon emissions. The mode shift from car to PT/active modes was 5.0%. More general traffic roads are likely to be removed for light rail options than metro and hybrid options.	light rail options and the hybrid option. The carbon emissions from the MSM modelling show carbon emissions from transport across Auckland producing 1,677,000 tCO2e/year, with option 2a with the lowest overall carbon emissions. The mode shift from car to PT or active modes was 6.5%.	corridors for cars and make driving a less attractive option. However, in this regard, light rail options perform better. Mode shift from this option is higher than light rail options but lower than light metro options. The carbon emissions from the MSM modelling show carbon emissions from transport across Auckland producing 1,678,000 tCO2e/year, with higher carbon emissions than light metro, but lower than light rail options.

9.7 Carbon emission reductions from the reduced demand for new roads

An impact of the light rail/light metro systems is that there will be a reduced need to travel by private vehicles on roads. This means that fewer roads need to be constructed. As part of the Method 3 calculations, an estimate was made for emissions savings from having to construct fewer roads.

9.7.1 Data log table

Table 30 shows the variables that were considered as part of this assessment

Table 30: Data log for assessing carbon reductions from reduced demand for new roads

Material impact	Dataset	Available for IBC MCA assessment?	Source
High	Car trips during the morning peak	Yes	MSM model outputs
High	Road cross sections + emissions factors	Yes	Arup's internal carbon insights platform for infrastructure, BRANZ CO2nstruct model, Greenhouse Gas Assessment Workbook for Road Projects[32]

9.7.2 Calculation methods & assumptions

Table 31 details the methodology and assumptions made for assessing carbon reductions from reduced demand for new roads.

Table 31: Methodology and assumptions made for assessing carbon reductions from reduced demand for new roads

Methodology	Assumptions
Calculate reduction in morning peak demand for private vehicle trips for each option	Peak hour travel demand factor of 0.6 was used to convert 2h peaks into 1h peaks.
Calculate number and length of vehicle lanes not required	Traffic lane capacity of 1000 veh/hour was used. Number of lanes required was rounded up, as part of a lane cannot be constructed. It was assumed there would be 2 trips per vehicle (one during the morning peak, and one during the evening peak).
Calculate area of car parking not required due to decreased vehicle trip demand	Each car park would require 30 m2 of space – for the car park and for manoeuvring, and each vehicle would require a car park space at the origin and destination of the trip.

[32] Waka Kotahi (2013). Greenhouse Gas Assessment Workbook for Road Projects. Available from: https://www.nzta.govt.nz/assets/resources/greenhouse-gas-assessment/docs/greenhouse-gas-assessment-workbook-road-projects.pdf

9.7.3 Results

The results show that there are fairly significant savings from the reduced need to construct new roads. Emissions reductions range from 14,700 to 19,000 tCO2e. Options 2b and 3 reduce car travel demand the most, so emissions reductions are highest for these options.

Table 32: Results of the road construction emissions assessment

Emissions savings from reduced need to build roads	Do Minimum	Options		
		Light Rail	Light Metro	Hybrid
		1B	2A	3
		Dominion	Sandringham	Sandringham
Car Trips (morning peak (2h) in Auckland)	711,886	703,031	702,124	702,335
Car trips not made		8,855	9,762	9,551
Peak hour travel demand (veh/h)		5,313	5,857	5,730
Number of lanes not required		6.0	6.0	6.0
Av. Trip Length (km)	11.5			
Equivalent Arterial Road Length not required - lane kms*		138	138	138
Emissions factor for roads (kgCO2e/m)	96.6			
GHG emissions savings - roads (tCO2e)*		13,333	13,333	13,333
Parking space not required (sq. m)		531,300	585,720	573,060

Material Volume - carpark (m3)		265,650	292,860	286,530
Emissions factor for carparks (kgCO2e/m3)	59.5			
GHG emissions savings - carparks (tCO2e)*		15,794	17,412	17,036
GHG emissions savings (tCO2e)*		**29,127**	**30,745**	**30,369**

**Modelled based off peak travel demand for 2051*

9.8 Carbon emission reductions from building houses in brownfield areas

Building houses in greenfield and brownfield areas produce different emission profiles. Dwelling typologies are different in greenfield and brownfield areas, and different dwelling types emit different levels of carbon emissions over their lifecycle. This assessment considers what the potential benefits might be from building light rail and light metro and how this would impact where future growth in Auckland will occur.

9.8.1 Data log table

Table 33 shows the variables that were considered as part of this assessment

Table 33: Data log for assessing reduced emissions from building houses along the corridor

Material impact	Dataset	Available for IBC MCA assessment?	Source
High	LCA of different housing typologies	Yes	3 sources were used to develop estimates for the lifecycle carbon emissions for different housing typologies: • A science-based approac to setting climate targets f buildings: The case of a New Zealand detached house[33] • A Life Cycle Assessment of Medium

[33] Chandrakumar et al. (2020). A science-based approach to setting climate targets for buildings: The case of a New Zealand detached house. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0360132319307723?via%3Dihub

			Density Houses in New Zealand[34] • New Zealand whole of life framework: LCAQuick v3.4[35]
High	Distribution of housing typologies across Auckland	Yes	Stats NZ, Building statistics
High	Population increases across the corridor	Yes	MSM model outputs
High	Change in distribution of housing typologies in the future	No	To get a more complete understanding on the potential emissions savings, estimates are needed on how the proportion of apartments and townhouses built across the corridor will change

9.8.2 Calculation methods & assumptions

Table 34 details the methodology and assumptions made for assessing operational emissions.

Table 34: Methodology and assumptions made for assessing emissions savings from building new houses

Methodology	Assumptions
Develop an understanding of the distribution of housing typology's (stand alone houses, apartments, and townhouses) in greenfield areas and along the corridor.	As consenting statistics do not distinguish between single-storey and double-storey houses, it was assumed that all new houses built are stand alone, single-storey houses. It is assumed that the proportion of newly consented houses, apartments, and townhouses in greenfield areas and along the CC2M corridor will stay the same in the future. However, it is likely a new rapid transit system along the corridor will increase the proportion of apartments and townhouses along the corridor. Houses built in the local board areas of Rodney, Hibiscus Coast, Waitakere Ranges, Howick, Papakura, and Franklin are all greenfield developments
Calculate emissions factors for new residential apartments, townhouses, and standalone single-storey houses.	Emissions estimates for building new townhouses and houses are taken from similarly sized townhouses and houses from reference cases
Calculate emissions factors for building new dwellings in greenfield areas and along the CC2M corridor.	All new houses along the corridor would have been built in greenfield areas without light rail/light metro, so emissions savings are the difference in emissions from building new dwellings along the corridor instead of building new dwellings in greenfield areas

[34] Ganda (2019). A Life Cycle Assessment of Medium Density Houses in New Zealand. Available from: https://researcharchive.vuw.ac.nz/xmlui/handle/10063/8649
[35] BRANZ (2021). LCAQuick: Life cycle assessment tool. Available from: https://www.branz.co.nz/environment-zero-carbon-research/framework/lcaquick/

Calculate emissions savings from building housing along the CC2M corridor per year	Emissions savings were calculated based off projected population increases along the corridor for each option.

Analysis of Auckland housing consenting data shows that greenfield developments are dominated by standalone single-storey housing. New housing built along the CC2M corridor has primarily been new apartments and townhouses. Additionally, average GFA for new townhouses in Auckland is 122 m2, and average GFA for standalone houses is 214 m2.

Table 35: Distribution of housing typologies in greenfield areas and along the CC2M corridor

	Houses	Apartments	Townhouses, units, and other
Greenfield areas	76%	2%	22%
CC2M	22%	53%	25%

Lifecycle analysis of each of the different housing typologies also show there are large differences in the construction and operational use of the housing typologies. In general, townhouses are the least carbon intensive housing typology, and standalone single-storey houses are the most carbon intensive. This primarily arises from the higher GFA in standalone single-storey houses in Auckland.

Table 36: Carbon emissions for different housing typologies (adjusted per person)

	Emissions factors (kgCO2e/year/person)
Residential: Multi-Rise Apartments	615
Residential: MDH Townhouses, Multi-Level	419
Residential: Detached, Single Storey	762

Estimates for the carbon impact of building houses in greenfield areas and along the corridor can be developed using the above tables. The analysis shows that accommodating future growth along the corridor will result in emissions savings of 85 kgCO2e/year/person. These emissions savings primarily arise from lower energy requirements in denser housing typologies.

Table 37: Carbon emissions factors for building housing in greenfield areas and along the CC2M corridor

	Emissions factors (kgCO2e/year/person)
Greenfield areas	684
CC2M	598
Emissions savings	85

9.8.3 Results

Using the above emissions factors and projected population increases along the corridor, estimates for the emission savings from accommodating growth along the corridor can be made. The results show that emissions savings range from 1,100 to 1,400 tCO2e per year. These estimates do not include construction emissions savings from reduced need to build infrastructure to support greenfield areas.

Table 38: Results of the operational emissions assessment

Emissions savings from building houses in CC2M corridor	**Do Minimum**	**Options**		
		Light Rail	**Light Metro**	**Hybrid**
		1B	**2A**	**3**
		Dominion	**Sandringham**	**Sandringham**
Population	259,688	306,227	341,132	341,132
Increase over do minimum		*46,539*	*81,444*	*81,444*
Emissions savings per year per person (kgCO2e/yr/person)		85		
Emissions savings per year (tCO2e/yr)		3,970	6,947	6,947

9.9 VEPM fleet and emission factors assumptions

The VEPM 6.1 model was used to inform the MSM model which were this assessment to predict emissions from vehicles emissions in Auckland. VEPM outlines the fleet composition assumptions for including light vehicles and bus fleet. The VEPM 6.1 fleet composition assumptions were applied for the do minimum and other 5 options for all years modelled in MSM.

Table 39: VEPM 6.1 assumptions adopted for MSM[36]

	Light duty vehicles <3.5tonnes										Heavy vehicles >3.5tonnes			
Year	Car petrol	Car diesel	Car hybrid	Car plug-in hybrid	Car electric	LCV petrol	LCV diesel	LCV hybrid	LCV plug-in	LCV electric	Diesel HCV	Diesel Buses	Electric HCV	Electric Buses
2001	72.5%	6.9%	0.0%	0.0%	0.0%	6.4%	7.9%	0.0%	0.0%	0.0%	6.0%	0.4%	0.0%	0.0%
2005	71.0%	7.9%	0.0%	0.0%	0.0%	5.0%	9.1%	0.0%	0.0%	0.0%	6.5%	0.5%	0.0%	0.0%
2010	70.1%	7.6%	0.2%	0.0%	0.0%	4.1%	11.0%	0.0%	0.0%	0.0%	6.4%	0.6%	0.0%	0.0%
2015	67.5%	7.8%	0.6%	0.0%	0.0%	3.5%	13.4%	0.0%	0.0%	0.0%	6.5%	0.6%	0.0%	0.0%
2020	64.2%	7.8%	1.2%	0.1%	0.3%	3.1%	16.0%	0.0%	0.0%	0.0%	6.5%	0.7%	0.0%	0.0%
2025	61.4%	7.6%	1.9%	0.7%	1.7%	3.1%	16.1%	0.0%	0.0%	0.2%	6.3%	0.7%	0.0%	0.0%
2030	54.5%	6.5%	3.0%	1.4%	7.8%	3.2%	15.5%	0.0%	0.0%	1.1%	6.0%	0.7%	0.3%	0.1%
2035	40.5%	4.5%	3.6%	2.2%	22.1%	3.1%	13.9%	0.0%	0.0%	3.2%	5.5%	0.7%	0.5%	0.1%
2040	26.6%	2.8%	3.1%	2.5%	37.7%	2.7%	11.3%	0.0%	0.0%	6.6%	4.8%	0.7%	1.0%	0.2%
2045	17.2%	1.7%	2.5%	2.5%	48.4%	2.2%	8.4%	0.0%	0.0%	10.4%	4.0%	0.6%	1.6%	0.4%
2050	12.5%	1.1%	1.8%	2.3%	54.3%	1.9%	6.3%	0.0%	0.1%	11.2%	3.2%	0.5%	2.2%	0.6%

9.10 Assessment accuracy

This chapter captures the accuracy of the carbon assessment to inform the level of confidence in the results. Table 40 summarises the accuracy for each carbon source assessment using a traffic light system to represent percentage of accuracy (see the key). It also captures the commentary to describe the data availability, completeness, and impact on emissions which informs the accuracy rating.

[36] https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Air-and-climate/Planning-and-assessment/Vehicle-emissions-prediction-model/VEPM-6.2-technical-report-2021.pdf

Table 40: Level of accuracy for carbon assessment

Red or orange or green to indicate accuracy of results based on data availability, and completeness of data	Emission source	Accuracy commentary
	User emissions.	Project and modelling data was used. 90% of the most impactful datasets were available for IBC carbon assessment. Most of the datasets were complete. The dataset not included in the IBC carbon assessment had a potentially high impact on carbon emissions.
	Construction emissions	45% of the recommended datasets for this assessment were available at IBC. If these most had partial data available. Project and reference project data was used. The datasets not included in the IBC carbon assessment were a combination of datasets that would have a potentially low or medium or high impact on carbon emissions.
	Operational emissions	Mostly complete data available at IBC. 40% of recommended datasets were available at IBC. Of these, most of the datasets were complete. Project and reference project data was used. The datasets not included in the IBC carbon assessment were a combination of datasets that would have a potentially low or medium or high impact on carbon emissions.
	Carbon emission reductions from the reduced demand for new roads	Project data and estimates was used. The key datasets required were included in the IBC carbon assessment.
	Carbon emission reductions from building houses in brownfield areas	Project data and estimates was used. The key datasets required were included in the IBC carbon assessment. The dataset not included in the IBC carbon assessment had a potentially high impact on carbon emissions.

KEY:
- 10-30% accuracy
- 30-70% accuracy
- 70%+ accuracy

The accuracy rating will improve as the design progresses and more datasets become available e.g. cost estimates bill of quantities.

10 Recommendations for DBC

It is recommended that the carbon assessment is conducted at each stage of the life cycle. This allows for increased confidence on results.

Figure 10-1 illustrates the importance of influencing low carbon projects earlier in the investment process. The PAS2080 allows for this through the actions set in for each of the work stages (shown in green). As more detailed and accurate information about the design becomes available more accurate analysis should be undertaken to determine a clearer projection of the whole of life carbon profile of ALR.

The figure also shows that during the concept phase (IBC stage) it is important to introduce a Low Carbon Design Principles in the project ALR Sustainability Strategy to ensure the detailed design adopts emission reduction interventions. This Strategy would also demonstrate how ISCA is used in the business case process.

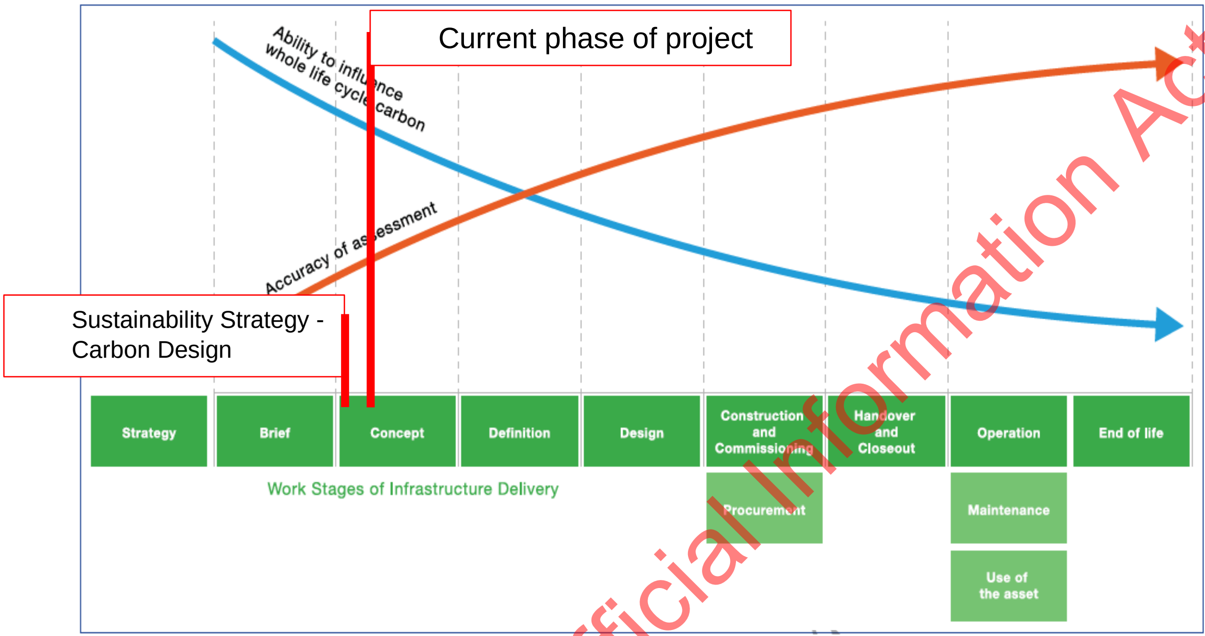

Figure 10-1: PAS2080 showing ability to influence carbon reduction across the life cycle of infrastructure delivery

Below is a list of the additional emissions that are recommended to be assessed in DBC once more detailed design information can be provided.

Operational emissions from the following assets:

- Station and depot operational requirements
- Trackside ventilation
- Lighting
- Asset maintenance
- Regenerative braking
- No of rolling stock
- Supporting infrastructure energy use
- Grid or private energy generation
- Renewable energy use %
- Backup generators
- Energy specifications of rolling stock

Construction emissions from the following activities:

- Transportation of materials
- New bridges
- Building retaining walls
- Manufacture of rolling stock

- Building depot
- Building culverts
- Building fencing
- At grade, tunnelled, and trenched rail tracks
- Volume of earthworks
- Building new stations
- Electricity usage for the TBM
- New/relocated utilities
- New roads

Transport user emissions from:

- TOD features at each station within 800m

Embodied WoL emissions profile for the Auckland Fleet

- Using VEPM 6.1 projections
- Vehicle efficiency factor
- GHG emissions