Prepared for
Major Projects Canberra
ABN: 66 676 633 401

Greenhouse Gas Assessment

09-Feb-2023

Light Rail City to Commonwealth Park

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Greenhouse Gas Assessment

Client: Major Projects Canberra

ABN: 66 676 633 401

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09-Feb-2023

Job No.: 60656949

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Executive Summary

Major Projects Canberra (MPC) proposes to extend the light rail from its current southern terminus at Alinga Street, City, to Woden (Light Rail to Woden). Light Rail to Woden is being progressed in two, self-contained stages for a faster Project delivery:

- Stage 2A City to Commonwealth Park (the Project)
- Stage 2B Commonwealth Park to Woden.

The Project involves extension of approximately 1.7km of track form and three new stops; Edinburgh Avenue Stop, City South Stop and Commonwealth Park Stop and supports the ACT Government's vision for a compact and efficient city and reaching net zero by 2045. AECOM Australia Pty Ltd (AECOM) were commissioned to undertake a greenhouse gas (GHG) assessment for the construction and operation of the Project, based on the design and information available at Works Approval (WA)/Development Application (DA) lodgement. As detailed design progresses, there may be adjustments to the types and quantities of inputs to the GHG assessment, with subsequent recalculation of GHG emissions undertaken. The following GHG emissions have been considered from the Project at the current stage:

- For construction the GHG emissions calculated include :
  - Combustion of liquid fuels from:
    - Stationary and mobile plant equipment and other vehicles
    - International shipping from import of light rail vehicles (LRVs) and batteries
  - Power consumption from the electrical grid
  - Embodied energy of:
    - Construction materials
    - Construction and demolition waste
    - LRVsand batteries
  - Vegetation clearing of urban street trees
  - Replanting of street trees (carbon sink)
- For operation the GHG emissions calculated include:
  - Power consumption from the electrical grid
  - Maintenance activities over the asset life including:
    - Combustion of liquid fuels from:
      - regular maintenance from street sweeping of light rails
      - Mobile equipment and international deliveries associated with major preventative maintenance activities
    - Embodied energy associated with replacement of LRVs and lithium-ion batteries and key materials identified during construction

The total emissions generated from construction by the Project were estimated to be 17,242t carbon dioxide equivalent ($CO_2{}^{-e}$), inclusive of Scopes 1, 2 and 3. The majority of the emissions are Scope 1 at 57% of the construction Project, which are emissions generated on site. Diesel fuelled mobile equipment has the highest contribution to Scope 1 emissions, followed closely by diesel fuelled lighting. Scope 2 emissions, which are due to electricity consumption from the grid equates to zero emissions due to the uptake of 100% renewable energy by ACT. Scope 3 emissions, which are emissions that are generated off site, however, are directly related to the Project in terms of offsite transport or GHG generation during the manufacture of materials and supplies, account for 43% of the construction Project.

The construction of the Project is expected to represent approximately 0.0035% of Australia's total emissions and 1.6% of ACT's total emissions, however, these Project-related GHG emissions are anticipated to be partially offset by minimising increases in GHG emissions from other forms of transport such as private motor vehicles and buses. In addition, Scope 1 and 2 Project GHG emissions will be offset.

Estimation of annual operational GHG emissions have been limited to Scope 2 emissions from electricity consumption from lighting, signalling, bore pumping and battery charging of LRVs at stations. The total estimated annual electrical consumption from the Project is 1,224,065 kWh; with the majority attributed to charging lithium-ion batteries. However, in the ACT electricity is 100% renewable and therefore Scope 2 emissions have a low CO_2 equivalent intensity; therefore, operation Scope 2 emissions from the Project are considered negligible.

GHG emissions from the Project from maintenance activities were estimated to be 7408 t CO_2^{-e} over an assumed asset life of 50 years. Approximately one third is attributed to Scope 1 emissions from fuel combustion; the remaining two thirds is Scope 3 emissions from fuel combustion associated with international imports and embodied energy in materials requiring replacement.

1.0 Introduction

AECOM Australia Pty Ltd (AECOM) has been commissioned to undertake a greenhouse gas (GHG) assessment for the construction and operation of Stage 2A City to Commonwealth Park Light Rail Project (the Project), based on the design and information available at Works Approval (WA)/Development Application (DA) lodgement.

The following report assesses the GHG emissions from the construction and operation of the Project.

1.1 Potential GHG Emissions from the Project

A quantitative assessment of GHG emissions due to construction and operation has been undertaken for the Project. As detailed design progresses, there may be adjustments to the types and quantities of inputs to the GHG assessment, with subsequent recalculation of GHG emissions undertaken. The following GHG emissions have been considered from the Project:

Construction sources of GHG emissions would include:

- Combustion of liquid fuels from:
  - Stationary and mobile plant equipment and other vehicles
  - International shipping from import of LRVs and steel rails
- Power consumption from the electrical grid
- Embodied energy of:
  - Construction materials
  - Construction and demolition waste
  - LRVs and batteries
- Vegetation clearing of urban street trees
- Replanting of street trees (carbon sink)

Operational sources of GHG emissions would include:

- Power consumption from the electrical grid
- Maintenance activities over the asset life including:
  - Combustion of liquid fuels from stationary and mobile plant equipment and other vehicles
  - Replacement of LRVs and LRV lithium batteries.
  - Embodied energy of materials

1.2 Report Scope

The scope of work for the report has been defined in **Table 1-1**.

Table 1-1 Scope of work and corresponding report section

Project scope item	Section
Project description	**Section 2.0**
Legislation and strategic context	**Section 3.0**
GHG and risk assessment methodology	**Section 4.0**
Construction assessment	**Section 5.0**
Operational assessment	**Section 6.0**
Conclusion	**Section 7.0**

2.0 Project description

Major Projects Canberra (MPC) proposes to extend the light rail from its current southern terminus at Alinga Street, City, to Woden (Light Rail to Woden). Light Rail to Woden is being progressed in two, self-contained stages for a faster Project delivery:

- Stage 2A City to Commonwealth Park (the Project)
- Stage 2B Commonwealth Park to Woden.

The Project is needed as part of a coordinated and holistic delivery of a series of major Projects in Canberra City and surrounds, to realise the strategic planning and development for Canberra City presented in the Territory Plan, the Transport for Canberra Plan and the National Capital Plan (NCP). The Project also supports the ACT Government's vision for a compact and efficient city and reaching net zero by 2045. Furthermore, the Project is a specific directive identified as a key strategy for developing and delivering an efficient, compact and sustainable Canberra City within the Moving Canberra Plan, The Light Rail Network Plan and The ACT Planning Strategy.

The Project would involve extending the CLR network from the current southern terminus at Alinga Street to a proposed stop at Commonwealth Park. A full Project description for the Project is provided in Chapter 3.0 of the Environmental Assessment.

The Project would include the following key elements:

- An extension of approximately 1.7 km of trackform, extending southbound via the western side of London Circuit before continuing on Commonwealth Avenue
- A new bridge across Parkes Way
- Three stops are proposed to be located at key points along the alignment to provide access to the light rail where there is expected to be high demand: Edinburgh Avenue Stop, City South Stop and Commonwealth Park Stop.
- One scissor crossover (crossover of railway tracks) to allow LRVs to reverse direction
- Utility, stormwater drainage and streetlighting adjustments, relocations and provisions
- Landscaping features sympathetic with Canberra's design as envisioned by the Griffins' along with requirements set out in other Territory and Australian Government policy
- 'Green tracks' running along Commonwealth Avenue and Northbourne Place that involve planting grass or shrubs between and besides the alignment
- Intersection layout, traffic signal phasing and road traffic speed changes along the alignment, including new intersections and modifications to existing intersections
- Pedestrian footpaths and crossing modifications
- Road widening and verge and kerb line changes.

The completed Project, including its key features and elements, is shown on **Figure 1**.

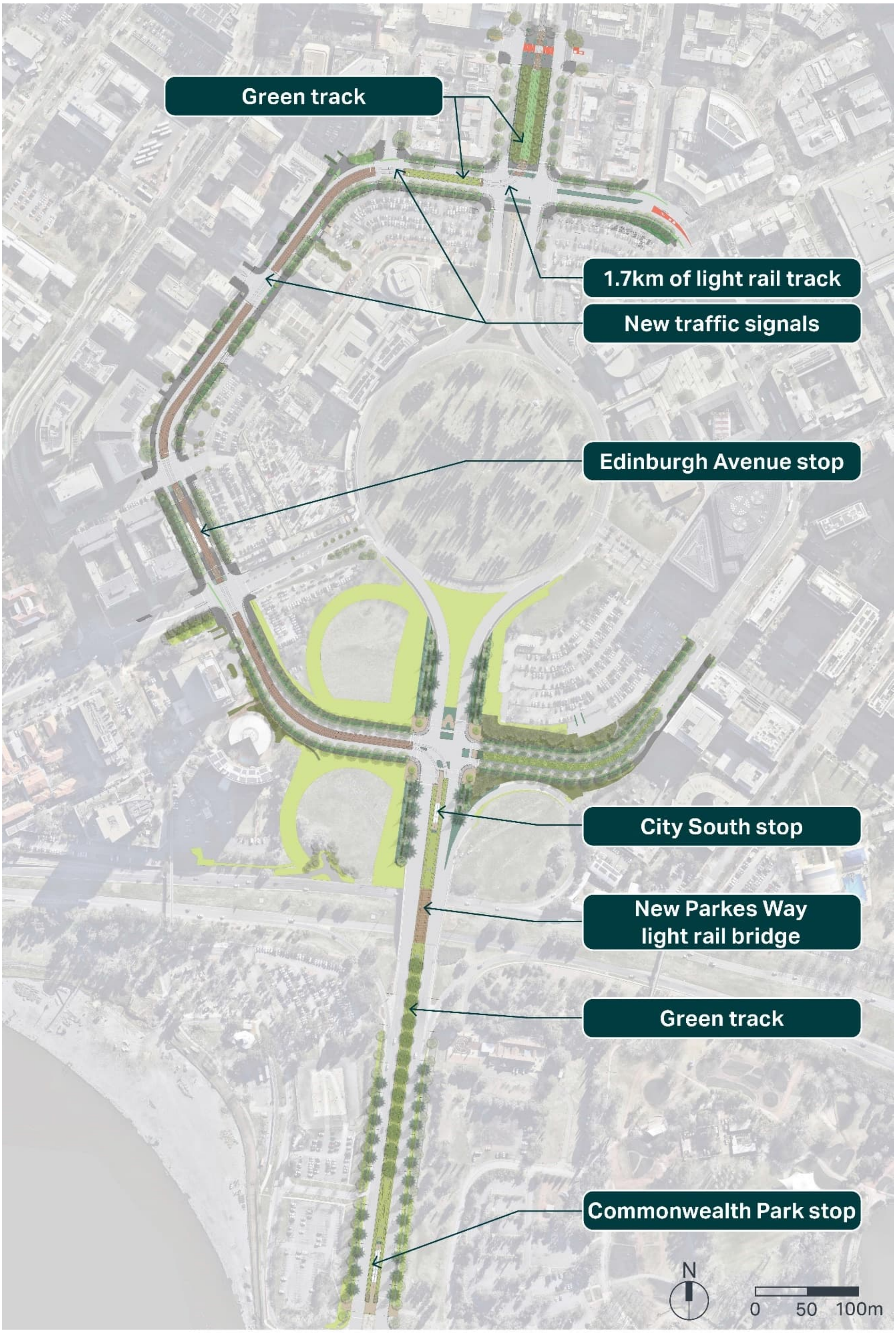

Figure 1 The Project and its key features

2.1 Construction

Construction activities associated with the Project would occur within a footprint referred to as the ‘delivery phase area’ (**Figure 2**). The operation of the Project would occur within a subset of the delivery phase area. The delivery phase area includes both Designated Land and Territory land. This GHG assessment addresses the Project in its entirety to allow for consideration of the Project as a whole.

Construction of the Project is anticipated to commence in 2024 with completion of construction planned in 2026. However, the duration of the construction would be dependent on final construction methodology and staging selected by the delivery contractor, as well as any efficiencies identified during the program. Following construction, a period of up to nine months would be required for testing and commissioning of the new light rail. Successful completion of the testing and commissioning programme would allow the Project Contractor to obtain accreditation from the Office of the National Rail Safety Regulator (ONRSR). Once complete, the system would be ready to be handed over for operation.

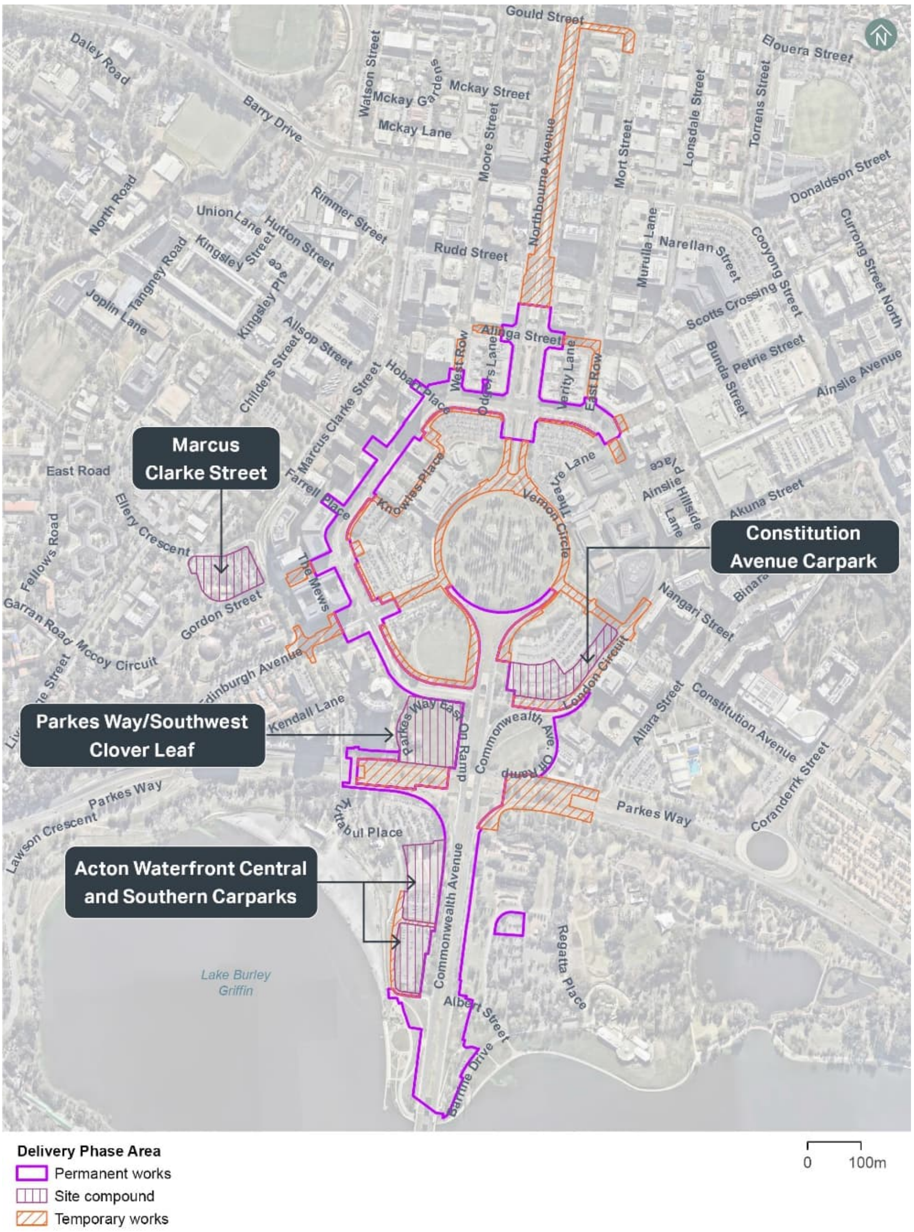

Figure 2 Delivery phase area

2.1.1 Site establishment and preparatory works

There would be four major compound sites, as shown on **Figure 2**. Several temporary construction compounds, stockpile sites and laydown areas would also be required as part of the Project. Upon completion of the works all established site compounds would be reinstated prior to handing back to the respective landowners.

There are utilities within the delivery phase area which are affected to various degrees by the Project. Most protection, decommissioning and removal of utilities would be completed early in the Project construction period, but may also be staged during the construction period depending on construction planning requirements.

Traffic management arrangements would include full and partial road closures and would introduce necessary traffic detours to direct the travelling public around work sites and construction access and egress points. Notification of these closures would be advertised in advance and sufficient time to deliver written notice would be required for the local businesses and residents. All temporary traffic management arrangements and diversionary routes would be agreed and approved by TCCS (RoadsACT) prior to implementation.

2.1.2 Construction strategy

The construction strategy of the Project has been divided by construction zones, major intersections and the Parkes Way bridge.

Table 2 Construction staging locations

Location	Description
Block closures	These are construction areas between major intersections. Block closures would be used to close off entire sections of the road network, typically between blocks to allow the Project contractor full access to the worksite and the best opportunity to complete the Project most efficiently. Stops would be constructed upon the occupation of the block section where it is located. Blocks include: • Northbourne Avenue (between Alinga Street and London Circuit) • London Circuit (between Northbourne Avenue and Petrie Plaza) • London Circuit (between Northbourne Avenue and West Row) • London Circuit (West Row to Knowles Place North) • London Circuit (between Knowles Place North and Gordon Street) • London Circuit (between Gordon Street and Edinburgh Avenue) • London Circuit (between Edinburgh Avenue and Commonwealth Avenue) • Commonwealth Avenue (between London Circuit and Parkes Way) • Commonwealth Avenue (between Parkes Way and Lake Burley Griffin).
Major intersections	The major intersections include Northbourne Avenue and Alinga Street, Northbourne Avenue and London Circuit, London Circuit and Edinburgh Avenue, London Circuit and Gordon Street and Commonwealth Avenue and London Circuit. For works within major intersections, wherever possible the construction of the intersection would be carried out during normal working hours, within the confines of a protected worksite. Closures, where required, are expected to be carried out over several weekends (typically from Friday 10pm to Monday 6am) for a maximum of 56 hours at a time, except during construction of track slab where a continuous 80 hours would be required to facilitate concrete curing and ensure adequate concrete strength is achieved prior to intersection reopening and eventual trafficking. The Commonwealth Avenue and London Circuit intersection would not require full closure, and would be subject to a contraflow arrangement for several weeks.

Location	Description
Parkes Way bridge	A new bridge would be built between the two road bridges on Commonwealth Avenue over Parkes Way. In appearance, the gap would be infilled to create a single surface. The new rail bridge would be supported on 8 concrete piles (four piles for each bridge abutment) and concrete-walled abutments. The construction of temporary roads allows for the continued movement of traffic during bridge construction activities, with the location of temporary roads selected by the contractor in line with the Roads ACT requirements.

2.2 Operation

The Project would be an extension of the Gungahlin to City service and would therefore have the same frequency. It would take approximately six to nine minutes to travel between Alinga Street and Commonwealth Park.

A minimum of five LRVs would be required for the expansion of the CLR network. The new LRVs would be similar in appearance, size and performance to those that operate on the current CLR network. These LRVs and modifications to the stabling yard at the Mitchell Depot would be complete prior to the operation of this Project.

A wire free track is proposed for the Project alignment with LRVs operating using onboard battery power supply between the current Alinga Street southern terminus and the proposed Commonwealth Park terminus. Battery storage capacity for additional and existing LRVs has been proposed to minimise visual impact in landscape and visual sensitive zones, such as Commonwealth Avenue.

Two track forms, a permanent form of rail infrastructure that provides a surface for rail vehicles to move, are required for the Project. One trackform would operate northbound and the other southbound, with a crossover installed on Commonwealth Avenue to allow LRVs to change direction. Green track would also be included as part of the Project, in three locations: Northbourne Place, London Circuit between Northbourne Avenue and West Row, and Commonwealth Avenue between London Circuit and Albert Street. Non-potable water would be used for the irrigation of the Commonwealth Avenue green track.

2.2.1 Changes to the road network

The proposed light rail track would run within a median between opposing vehicular traffic flows for the entire length of the proposed alignment. The median would be between 80-150 mm high between intersections to minimise the possibility of road vehicles straying into the rail corridor. The median height would transition to be at grade just before each signalised intersection. This would facilitate vehicular and pedestrian movement across the track.

Road network changes required to accommodate the Project’s median light rail alignment and associated stops are provided in **Table 3**

Table 3 Lane configuration

Road	Proposed lane configuration
London Circuit	• The lane arrangement on London Circuit between Edinburgh Avenue and Commonwealth Avenue would remain unchanged • Two 3.3m wide traffic lanes in each direction along London Circuit between Northbourne Avenue and West Row, including a dedicated westbound right turn lane to West Row • A single 3.7m wide traffic lane in each direction along London Circuit between West Row and Edinburgh Avenue, except on the southbound approach to Gordon Street which would have a dedicated right turn lane • The posted speed limit along London Circuit would remain 40km/h except in the vicinity of the Edinburgh Avenue stop where the speed would be reduced to 20km/h because of the high pedestrian activity expected at the stop • All on street parking and loading along London Circuit would be removed

Road	Proposed lane configuration
	• Two new signalised intersections on London Circuit to facilitate right turns across the Project's alignment at West Row and University Avenue. The remaining unsignalised intersections along London Circuit would be converted to left-in/left-out out[1].
Alinga Street	One lane in each direction on Alinga Street within the median on Northbourne Avenue. These lanes would be for buses only.
Commonwealth Avenue	No change
Northbourne Avenue	No change

2.2.2 Active transport infrastructure

The Project includes walking and cycling facilities or upgrades that aim to improve pedestrian and cyclist safety, connectivity and amenity within the study area, and in particular along London Circuit West and Commonwealth Avenue. Active transport infrastructure includes dedicated and separate pedestrian and cycling paths.

[1] Right turn out from Knowles Place south permitted by emergency vehicles under signals

3.0 Legislative and strategic context

3.1 Overview

GHG emission reduction goals are periodically set at a global level, and voluntarily adopted by countries around the world. Individual states and territories in Australia further detail their GHG reduction strategies by implementing policies and plans, with reporting of GHG emissions also standardised through an approved reporting scheme. Relevant global and Australian policies and strategies are introduced below.

3.2 International policies and commitments

3.2.1 United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) aims to stabilise GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. It was entered in to force in 1994, and currently has 197 countries (including Australia) that are parties to the convention. The convention also puts the onus on developed (Annex I) countries to lead the way in GHG emissions reduction, requiring them to report regularly on their climate change policies and measures. Annex I countries are also required to submit an annual inventory of their GHG emissions

3.2.2 Kyoto Protocol

The Kyoto Protocol was adopted in 1997, entered in to force in 2005 and currently has 192 countries, including Australia, that are parties to the protocol. The aim of the protocol is to implement the objective of the UNFCCC, covering the six GHG: carbon dioxide (CO_2), methane (CH_4), N_2O, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The protocol only binds Annex I countries as they are largely responsible for the current high levels of GHG. Primarily countries must meet emission reduction targets nationally, however there are flexibility mechanisms available including international emissions trading.

3.2.3 The Paris Agreement

The Paris Agreement is an international treaty on climate change, was adopted by 196 parties, including Australia, in 2015 and entered in to force in 2016. The aim of the agreement is to limit global warming to below 2°C, and preferably 1.5°C compared to pre-industrial levels. The main driver to limit warming is reducing GHG emissions, and the countries partied to the agreement are required to submit plans on a five-year cycle outlining the actions they will take to reduce emissions. The agreement also puts a focus on best practice technologies for reducing GHG emissions but also adapting to climate change.

Under the Paris Agreement, to which Australia is a Party, countries are required to communicate their Nationally Determined Contribution (NDC) which sets out their emissions reduction ambitions. On 16 June 2022, Australia communicated its updated NDC under Article 4 of the Paris Agreement to the UN. This updated NDC included confirmation of Australia's commitment to achieve net zero emissions by 2050, and a new, increased, 2030 target of 43% below 2005 levels by 2030.

While Australia's NDC as part of the Paris Agreement outlines the countries emission reduction targets, this is yet to be formerly legislated nationally. The Climate Change Bill 2022 discussed in **Section 3.4.1** if passed will ensure that Australia's emissions reduction targets are not just recorded in international settings but are clearly stated in Australia's domestic law.

3.3 National Policies

3.3.1 The Climate Active Carbon Standards

The Climate Active Carbon Standards set out the minimum requirements for calculating, reducing, offsetting, auditing, and reporting on emissions based on international standards and tailored to Australia. The climate active carbon standards include standards for business operations, products and services, events, precincts, and buildings.

3.3.2 Zero Emissions Government Fund

The Zero Emissions Government Fund is the key mechanism for supporting cost effective emission reduction Projects in Government operation. The fund is designed to support emission reduction Projects by providing interest free loans to Government agencies for Projects that cut emissions from natural gas and transport. Energy bill savings are used to repay loans, continually replenishing the fund. The Zero Emissions Government fund supports the ACT Government under the Environment, Planning and Sustainable Development Directorate (EPSDD) objective to move towards a zero emissions government by perusing rapid emission reduction targets of greater than 33% reduction in emissions from government operations by 2025 (from 2020 levels) and zero emissions by 2040. Additional GHG ACT policy information is discussed in **Section 3.5.**

3.3.3 Low emissions technology focuses

The Australian government has a current focus of investing and encouraging low emissions technologies. Of relevance to this Project is the future fuels strategy and encouraging electric vehicle use.

3.3.4 National Greenhouse and Energy Reporting Scheme

The National Greenhouse and Energy Reporting Scheme (NGER) is the national framework used for reporting company information about GHG emissions, energy production and energy consumption. If a facility or corporate groups reach the applicable threshold, they have an obligation under the *National Greenhouse and Energy Reporting Act 2007* (Cth) to report CO_2^{-e} emissions.

Under section 10 of the *National Greenhouse and Energy Reporting Act* 2007 allows for the provision of the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (amended 1 July 2021) legislative instrument. This determination provides for the measurement of:

a. GHG emissions arising from the operation of facilities

b. The production of energy arising from the operation of facilities

c. The consumption of energy arising from the operation of facilities.

The determination provides four methods and criteria for the measurement of Scope 1 and Scope 2 GHG emissions (refer to **Section 4.1.3** for a description of Scope 1 and Scope 2 emissions). The four methods used for estimation include:

- **Method 1** (default method) - derived from the National Greenhouse Accounts methods and is based on national average estimates
- **Method 2** - facility specific method using industry practices for sampling and Australian or equivalent standards for analysis
- **Method 3** - same as Method 2 but is based on Australian or equivalent standards for both sampling and analysis
- **Method 4** - facility specific measurement of emissions by continuous or periodic emissions monitoring.

Scope 1 emissions for the construction of the Project have been estimated using Method 1. Emissions estimation methodology for both Scope 1 and Scope 2 emissions from the Project are discussed in more detail in **Section 4.1**, **Appendix A** and **Appendix B**.

3.4 National bills promoting legislation of GHG emissions

3.4.1 Climate Change Bill 2022

On the 27 July 2022 the Commonwealth Government introduced the Climate Change Bill 2022. The Bill proposes to set Australia's GHG emissions reduction targets into law, similar to climate target laws enacted in other OECD nations. The Bill is comprised of five key elements:

1. To legislate Australia's GHG emissions reduction targets, being a 43% reduction from 2005 levels by 2030 and net zero emissions by 2050

2. To require the Minister for Climate Change to deliver an annual statement, within six months of each financial year, to Parliament describing:
    - Australia's progress towards achieving its emissions reduction targets
    - Relevant international developments
    - Climate change policy
    - The effectiveness of Commonwealth climate change policies in contributing to achieving the targets and reducing emissions in relevant
    - The impacts and benefits of the Commonwealth's climate change policies on rural and regional Australia
3. To ensure the Climate Change Authority provide advice to the Minister for Climate Change in relation to the annual statement.
4. To ensure the Climate Change Authority advise the Minister for Climate Change at least every five years in relation to:
    - The setting of future emissions reduction targets to be included in new Nationally Determined Contributions
    - Emissions reduction targets in adjusted Nationally Determined Contributions
5. To provide for periodic reviews of the operation of the legislation.

3.4.2 Climate Change (Consequential Amendments) Bill 2022

Introduced simultaneously to the Climate Change Bill 2022 the Climate Change (Consequential Amendments) Bill 2022 makes consequential amendments to existing federal legislation (14 Acts in total). The proposed changes support the Climate Change Bill 2022 to enable consideration of the GHG emission reduction targets when specified agencies are exercising powers or performing functions. The proposed amendment embeds consideration of Australia's GHG emissions reduction targets and the Paris Agreement into the objects and functions of a range of Commonwealth entities and schemes, helping ensure those entities and schemes can contribute to the delivery of those targets. Some entities, such as those with a research and commercialisation focus, also have a role providing a foundation for Australia to achieve new or adjusted targets over time.

3.5 Territory Policy

3.5.1 ACT Climate Change Strategy 2019-2025

The ACT Climate Change Strategy has set a goal of net zero emissions for the entire territory by 2045. 100% supply of electricity from renewable sources was the target for 2020, with the focus moving on to reducing emissions from transport and gas, which are not as easily controlled by the government as electricity supply. The strategy sees the government providing the services, incentives, and regulatory framework to support change amongst the community and businesses.

4.0 Methodology

4.1 Greenhouse gas assessment

4.1.1 Greenhouse gas accounting

The calculation methodology utilised to assess the GHG contribution of the Project is as outlined in the National Greenhouse and Energy Reporting Act 2007 and the accompanying National Greenhouse and Energy Reporting (Measurement) Determination 2008 (amended 1 July 2021).

Scope 1 emissions have been estimated using the default method (Method 1) using GHG emission factors listed in The National Greenhouse Accounts Factors, Australian National Greenhouse Accounts (Commonwealth of Australia 2021) (NGA) to assess the GHG contribution of the Project.

Calculation of Scope 2 emissions has incorporated an ACT specific emission factor for electricity consumption as published within ACT Greenhouse Gas Inventory for 2020-21 (ACT, 2021). This accounts for the increased reliance on renewable energy within the ACT as opposed to the NGA emission factor for ACT/NSW which is considerably higher to reflect the higher reliance on fossil fuels within the state of NSW.

In addition, the following guidelines and tools were used for the assessment[2]:

- Transport for NSW (TfNSW) Carbon Estimate and Reporting Tool (TfNSW, 2017)
- Greenhouse Gas Assessment Workbook for Road Projects (TAGG, 2013).

4.1.2 Greenhouse gases assessed

All expected activities were analysed to determine emission sources and likely greenhouse pollutants. The Project is likely to have both direct and indirect emissions. Direct emissions are produced from activities controlled by the proponent, such as construction activity. Indirect emissions are generated in the wider economy as a consequence of the Project, such as goods and services required to facilitate the Project, with electricity the most significant category of indirect emissions. CO_2 is considered to be the most significant GHG emission for the Project, however the emission factors from NGA also take into account methane, NOx, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride.

GHG emissions have been reported as $CO_2{}^{-e}$, a metric measure used to compare the emissions from various GHG on the basis of their global warming potential by converting amounts of other gases (e.g. NO_x) to the equivalent amount of CO_2 with the same global warming potential.

GHG emission sources for construction are discussed in **Section 5.0** and would include:

- Combustion of liquid fuels from:
  - Stationary and mobile plant equipment and other vehicles
  - International shipping from import of LRVs and steel rails
- Power consumption from the electrical grid
- Embodied energy of:
  - Construction materials
  - Construction and demolition waste
  - LRVs and batteries
- Vegetation clearing of urban street trees
- Replanting of street trees (carbon sink).

GHG emission sources from operation are assessed in **Section 6.0** and would include:

[2] The National Greenhouse and Energy Reporting (Measurement) Determination 2008 deals with Scope 1 emissions and Scope 2 emissions. Supplementary Material in TAGG 2013 and CERT 2017 has been used for estimating Scope 3 emissions for the Project.

- Power consumption from the electrical grid both annually and over the asset life
- Maintenance activities over the asset life including:
  - Fuel combustion associated with:
    - Regular maintenance from street sweeping of light rails
    - Mobile equipment and international deliveries associated with major preventative maintenance activities
  - Embodied energy associated with replacement of LRVs and lithium-ion batteries and key materials identified during construction.

4.1.3 Scope of emissions

To quantify GHG emissions from the Project the ‘boundary’ of the assessment has been defined above in Section 4.1.2 by defining which emission sources and activities are included in the technical report. Emissions are then further characterised by scope, determined by the origin of the emissions. Scope 1 emissions are direct GHG emissions that are produced by activities that are controlled by the proponent, while Scope 2 and 3 emissions are indirect emissions that are a result of activities associated with the Project.

Scope 1

Scope 1 emissions are direct GHG emissions that are produced by activities that are controlled by the proponent. Scope 1 are calculated from direct emission factors which give the CO_2^{-e} at the point of release within the boundary of the Project.

Examples of Scope 1 emissions include combustion liquid fuels such as diesel used in construction vehicles and mobile plant equipment. Scope 1 emissions also include the clearing of vegetation (resulting in a lost carbon sink) removal. While the Project includes the removal of some urban trees, additional established trees are also expected to be planted as part of future landscaping works; with a Project objective of 30% canopy cover in accordance with Transport Canberra and City Service (TCCS) guidelines. The Project also incorporates the use of green track. Assessment of GHG emissions for the Project included both loss of carbon sink from the removal of trees and the beneficial effects of additional street planting (re-introducing carbon sinks).

Scope 2

Scope 2 indirect GHG emissions are a result of activities associated with the Project from the consumption of electricity, heating, cooling or steam that is produced offsite. Scope 2 emissions are calculated from electricity consumed during construction and operation. These emissions are dependent on the origin of the electricity and based on burning fossil fuels at the power station, outside of the Project boundary. In the ACT, electricity is sourced from 100% renewables and therefore Scope 2 emissions have a low CO_2^{-e} intensity (ACT Government 2017) based on the rate of electrical consumption.

The most significant source of Scope 2 emissions for the Project during construction would be from electricity from the grid at site compounds. Scope 2 emissions from construction have been quantified in Section 5.0 to assess the potential GHG emissions from construction of the Project.

During operation the most significant source of Scope 2 emissions from the Project would be from power supply to the three light rail stops and charging of on-board lithium-ion batteries.

Scope 3

Scope 3 emissions are indirect emissions that have not been accounted for in Scope 2. Scope 3 emissions are generally referred to as embodied emissions and refer to the emissions created over the entire lifecycle of a material from creation to disposal, not including direct emissions from usage.

Scope 3 emissions are not reported under the NGER scheme, however primary Scope 3 emissions for the Project during construction would include transport of construction materials (such as concrete, steel, asphalt, aggregate and sand). Embodied energy within key construction materials and disposal of waste generated by the Project have been included in this assessment.

Embodied energy associated with construction of the five new LRVs has been considered for the Project and is based on the estimated steel quantity and on-board batteries. Retrofitting of the existing 14 LRVs with batteries has also been accounted for.

Embodied energy from construction factors have largely been based on emission factors for Australian resources. In exception to this embodied energy associated with rail steel and LRV's which have been based on more conservative international emission factors. Similarly embodied energy for LRV batteries have also been based on international factors. Additional information on international emission factors is provided in Appendix A.

4.1.4 Assumptions and limitations

Data was supplied for the purpose of this assessment, based on best estimates from the current Project design. It is assumed that these quantities will not be 100% accurate due to variations in the Project over the construction period. If any quantities are changed significantly, especially concrete and steel estimates, then this assessment should be revisited and verified for accuracy.

Where quantities of fuel were not able to be supplied, calculations were made considering estimated run time and typical fuel consumption rates by equipment type.

The Project is planned to begin construction in 2024, with completion of construction planned in 2026. Emission estimates for the Project have been compared to both ACT and National GHG emissions for the 2020 reporting year and are therefore considered conservative.

NGA Scope 2 reporting factors for ACT includes electrical consumption from NSW which is heavily reliant on fossil fuels and is not considered representative of ACT emission factors which currently rely on 100% renewable electricity (ACT, 2021). As such a zero emission factor has been adopted based on the ACT Greenhouse Gas Inventory for 2020-21 electricity supply to the ACT has been adopted.

Some emissions from the Project have been omitted as they are considered immaterial. In accordance with Greenhouse Gas Assessment Workbook for Road Projects (TAGG, 2013) emissions are not required to be calculated if they are likely to be less than 5% of the total Project emissions. On this basis, small material quantities such as timber formwork, road furniture and other miscellaneous items were not considered. Scope 3 emissions have been limited to transport and embodied energy of key construction materials and disposal of waste generated by the Project. Where construction materials have been sourced outside Australia (steel rails and for LRVs) Scope 3 embodied energy has accounted for international emission factors. Fuel usage apportionment from container ships used to import rail steel and LRVs and road transport associated with road transport has also been included in Scope 3 emission calculations. Scope 3 emission calculations for international imports has been limited to LRVs and steel rails.

For maintenance regular maintenance emissions, calculations have been limited to street sweeping of rails. For major preventative maintenance activities, emissions have been limited to replacement of LRV's and batteries and fuel usage and embodied energy associated with replacement of key construction materials with a product life of less than the assumed asset life of 50 years.

Additional information regarding assumptions made for the GHG inventory for the Project are detailed in **Appendix A.**

5.0 Construction

5.1 Assessment of emissions

This section details the estimated quantities of GHG generating materials and activities for the Project for construction. GHG estimates for the Project have been calculated using emission factors from the following documentation:

- The National Greenhouse Accounts Factors, Australian National Greenhouse Accounts (Commonwealth of Australia 2021)
- ACT Greenhouse Gas Inventory for 2020-21 (ACT, 2021)
- Greenhouse Gas Assessment Workbook for Road Projects (TAGG, 2013)
- Carbon Estimate and Reporting Tool Manual, (Transport for NSW 2017)
- GHG Emissions from the Production of Lithium-Ion Batteries for Electric Vehicles in China (Han Hao *et al* 2017).

A detailed description of adopted emission factors and key inputs and assumptions are provided in **Appendix A**. **Table 4** provides a summary of the estimated GHG emissions from the Project, categorised by scope, source group and activity type. A more detailed emissions inventory for individual emission sources is also provided in **Appendix A** for individual sources.

The total emissions generated from construction of the Project are estimated to be 17,242t CO_2-e, inclusive of Scopes 1, 2 and 3. The majority of the emissions are Scope 1 at 57% of the construction Project, which are emissions generated on site. Diesel fuelled mobile equipment has the highest contribution to Scope 1 emissions, followed closely by diesel fuelled lighting. Scope 1 also includes some carbon sequestration due to the planting of new trees, green track and ground cover. Scope 2 emissions, which are due to electricity consumption from the grid equates to zero emissions due to the uptake of 100% renewable energy by ACT. Scope 3 emissions, indirect emissions related to the Project in terms of offsite transport or GHG generation during the manufacture of materials and supplies, account for 43% of the construction Project.

The Project is assumed to emit approximately one third of the above emissions per year, during the construction period. Realistically due to the staging of construction activities this will not be completely accurate, however for the purposes of determining Project life emissions it is not deemed significant.

In 2020 Australia's total GHG emissions were 497.7 megatonnes (Mt) CO_2^{-e}, with ACT contributing 1.1 Mt CO_2^{-e} (DISER, 2022). In comparison, construction of the Project is expected to represent approximately 0.0035% of Australia's total emissions and 1.6% of ACT's total emissions annually. This is a conservative comparison noting the Projects GHG contribution of 17,242 t CO_2^{-e} would be distributed over the entire length of the construction period.

Table 4 Summary of Scope 1, 2 and 3 Construction GHG emissions for the Project as CO_2 equivalent

Scope Type	Emission Source	Activity Category	Qty	Unit	Emission Factor	Unit	GHG emissions (t $CO_{2\text{-e}}$)	Total (t CO2-e)	Contribution (%)
Scope 1	Fuel combustion	Generators	460	kL	2.7	t CO_2-e/kL	1,247	9,833	57%
		Mobile equipment	1,890	kL	2.7	t CO_2-e/kL	5,156		
		Lighting	847	kL	2.7	t CO_2-e/kL	2,307		
		Light vehicles (onsite)	459	kL	2.7	t CO_2-e/kL	1,242		
		Deliveries (onsite)	4.0	kL	2.7	t CO_2-e/kL	11		
		Waste transport (onsite)	2.4	kL	2.7	t CO_2-e/kL	6.5		
	Vegetation removal (loss of carbon sink)	Medium tree removal	100	Trees	1550	kg CO_2 sequestered/tree	155		
	Landscaping (new carbon sink)	Tree planting	145	Trees	1550	kg CO_2 sequestered/tree	-225		
		Green track	0.51	Hectares	110	t CO_2-e/ha	-56		
		Ground cover	0.10	Hectares	110	t CO_2-e/ha	-11		
Scope 2	Electricity consumption	Renewable energy consumption	9,144,392	kWh	0	t CO_2-e/kWh	0	0	0%
Scope 3	Fuel combustion	Deliveries (offsite)	138	kL	0.14	t CO_2-e/kL	19	7,408	43%
		Waste transport (offsite)	10	kL	0.14	t CO_2-e/kL	1.3		
		Light vehicles (offsite)	521	kL	0.14	t CO_2-e/kL	72		
		International imports (shipping)	8,568,352	freight tonne kilometres (tkm)	0.00893	kg CO_2e-/tkm	77		
		International imports (road transport)	298,368	tkm	0.07260	kg CO_2e-/tkm	22		
	Waste	Earthwork and materials	76,080	Tonnes	0	t CO_2-e/t	0		
		General solid waste	5,530	Tonnes	0.2	t CO_2-e/t	1,106		
	Embodied energy	LRV – steel	208	Tonnes	3000	kg CO_2-e/t	624		
		LRV – lithium batteries	2586	kWh	135.7	kg CO_2-e/kWh	351		
		Asphalt	4899	Tonnes	65	kg CO_2-e/t	318		
		Glass	2.7	Tonnes	1095	kg CO_2-e/t	3		
		Sand	705	Tonnes	4.3	kg CO_2-e/t	3		
		Pavement – stone	866	Tonnes	93	kg CO_2-e/t	81		
		Pavement – brick	6	Tonnes	0.38	t CO_2-e/t	2		
		Pavement - concrete	32	m^3	398	kg CO_2-e/m^3	13		
		Drainage	1425	Tonnes	280	kg CO_2-e/t	399		
		Steel	542	Tonnes	2800 - 3400	kg CO_2-e/t	1741		
		Concrete – ready mix	16,416	Tonnes	0.155	t CO_2-e/t	2,544		
		Concrete – pre-cast	79	m^3	398	kg CO_2-e/m^3	31		
							TOTAL	**17,242**	

5.2 Emission management and mitigation measures

Several GHG emission management and mitigation measures have been identified for the Project during construction, considering general emission reduction strategies of avoid, reduce or replace emissions where possible. The management and mitigation measures are detailed in **Table 5-5** below.

Table 5-5 Construction management and mitigation measures

Ref	Management and mitigation measure	Timing
C1	Implement energy efficient guidelines for operational works such as a 'no-idling' policy for all construction vehicles and plant to switch of engines when not in use	During construction
C2	The following measures to manage greenhouse gas emissions would be implemented: • Only use petrol or diesel generators where mains power is not feasible • Keep vehicles and construction equipment operating on site well maintained and turned off when not operating (minimise idling on the site) • Energy efficiency measures for fixed construction components such as site offices, including solar panels and timer-controlled lighting • Consider other appropriate methods for reducing diesel use such as use of biodiesel or ethanol blends where feasible • Use solar powered lights/message signs as appropriate.	During construction
C3	To reduce Scope 3 emissions where feasible: • Select materials with lower embodied energy values and for high embodied energy materials (such as concrete, steel and asphalt) reduce or substitute quantities • Select local materials or Australian materials over imported materials to minimise transport emissions. Minimise construction waste	Detailed design and during construction
C4	Carbon offsets would be retired at the completion of construction to account for emissions associated with the construction of the Project to achieve a zero net carbon footprint for all Scope 1 and 2 emissions.	Post construction

5.3 Residual emissions

The above management and mitigation measures would help to reduce GHG emissions, however GHG emissions would still result as a part of the Project. The longer-term benefits of the Project once operational are expected to result in a net positive effect on GHG emissions by utilising the ACT's zero carbon electricity grid to power the LRV's whilst also removing a portion of privately owned combustion fuelled cars from the road network.

6.0 Operation

6.1 Assessment of emissions

This section details the estimated quantities of GHG generating materials and activities from operation and maintenance of the Project and have been reported on an annual basis. GHG estimates for the Project have been calculated using emission factors from the following documentation:

- The National Greenhouse Accounts Factors, Australian National Greenhouse Accounts (Commonwealth of Australia 2021)
- ACT Greenhouse Gas Inventory for 2020-21 (ACT Government 2021)
- Greenhouse Gas Assessment Workbook for Road Projects (TAGG, 2013)
- GHG Emissions from the Production of Lithium-Ion Batteries for Electric Vehicles in China. Sustainability 2017 9(4) 504 (Han Hao *et al* 2017).

A detailed description of adopted emission factors and key inputs and assumptions are provided in **Appendix B**. **Table 7** provides a summary of the estimated GHG emissions from the Project, categorised by scope, source group and activity type. A more detailed emissions inventory for individual emission sources during operation is provided in **Appendix B**.

Estimation of operational GHG emissions have been limited to Scope 2 emissions from electricity consumption from lighting, signalling, bore pumping and battery charging of LRVs at stations. In the ACT, electricity is 100% renewable and therefore Scope 2 emissions are assumed to have an emission factor of 0 tCO_2^{-e} /kWh (ACT Government 2021). While the effective GHG emissions generated from renewable energy are considered negligible, electrical consumption is reported for transparency. The total estimated annual electrical consumption from the Project is 1,224,065 kWh or 61,203 MWh over and assumed asset life of 50 years.

GHG emissions from the Project from regular maintenance have been limited to fuel consumption from street sweeping of rails once per month; with an estimated Scope 1 emissions of 0.03 t CO_2e- annually. In addition to regular maintenance, emissions for major preventative maintenance activities have also been estimated over a 50 year asset life, from fuel use (Scope 1 and Scope 3) as well as from embodied energy (Scope 3). Major preventative maintenance activities have been limited to key materials identified for construction works with a product life equal to or less than 50 years. Total emissions from maintenance of the Project over the assumed asset life is 7,606 tCO_2^{-e} which is comprised of approximately one third Scope 1 emissions and two thirds Scope 3 emissions.

6.2 Management and mitigation measures

Table 6-1 Operational management and mitigation measures

Ref	Management and mitigation measure	Timing
O1	Development and implementation of a **Carbon and Energy Management Plan** to support the reduction of ongoing emissions associated with maintenance activities	During operation

6.3 Residual emissions

The above management and mitigation measures would help to reduce GHG emissions, however the longer-term benefits of the Project are expected to result in a net positive effect on GHG emissions by using zero carbon electricity to power the LRVs whilst also removing a portion of privately owned combustion fuelled cars from the road network.

Table 7 Summary of Scope 1, 2 and 3 Operational and Maintenance GHG emissions for the Project as CO_2 equivalent per annum

Scope Type	Emission Source	Activity Category	Qty	Unit	Emission Factor	Unit	Annual GHG emissions (t CO_{2}-e)	Asset Life: Total GHG Emissions (t CO_{2}-e)	Asset Life: Scope Total
Operation									
Scope 2	Electricity consumption	Bore pump	2555	kWh	0	kg CO_{2}-e/kWh	0	0	0
		Signalling	89878	kWh	0	kg CO_{2}-e/kWh	0	0	
		Lighting (stations)	29119	kWh	0	kg CO_{2}-e/kWh	0	0	
		Lighting (street)	290131	kWh	0	kg CO_{2}-e/kWh	0	0	
		Traction / charging	812,383	kWh	0	kg CO_{2}-e/kWh	0	0	
		Bore pump	2555	kWh	0	kg CO_{2}-e/kWh	0	0	
Note: Scope 2 emissions have been assumed to have an emission factor of zero due to the use of renewable energy the total electrical consumption is 1,224,065kWh. Based on the National Greenhouse Account Factors (DCCEEW, 2021) emission factor of 0.79 kg CO_{2}-e/kWh for NSW this would equate to 967t CO_{2}-e Scope 2 emissions annually.									
Maintenance									
Scope 1	Fuel combustion	Street Sweeping	0.01	kL/year	70.2	kg CO_{2}-e/GJ	0.03	1.51	2535
		Asphalt works	82.3	kL	70.2	kg CO_{2}-e/GJ		223	
		Pavement works	425.5	kL	70.2	kg CO_{2}-e/GJ		1153	
		Concrete works	427.2	kL	70.2	kg CO_{2}-e/GJ		1158	
Scope 3	Fuel combustion	International shipping	3,322,643	tkm	0.00893	kg CO_{2}-e/tkm		30	5071
		Road Transport	56,448	tkm	0.0726	kg CO_{2}-e/tkm		4	
	Embodied energy	LRV (steel)	208.1	tonnes	3000	kgCO_2e-/t		624	
		LRV (lithium batteries)	18098.6	kWh	135.7	kgCO_2e-/kWh		2456	
		Asphalt	4899.0	tonnes	65	kgCO_2e-/t		318	
		Pavement (footpaths) - stone	1731.3	tonnes	93	kg CO_2-e/t		161	
		Pavement (footpaths) - brick	12.6	tonnes	0.38	t CO_{2}-e/t		5	
		Pavement (footpaths) - concrete	64.8	m^3	398	kg CO_{2}-e/m3		26	
		Concrete - ready mix	9199.2	tonnes	0.155	tCO_2-e/t		1426	
		Concrete - precast	52.6	m^3	398	kg CO_{2}-e/m^3		21	

7.0 Conclusion

AECOM was commissioned to undertake a GHG assessment for the construction and operation of the Project using information avail at the time of WA/DA lodgement.

The construction period was assumed to commence in early 2024 and be completed by late 2026 and construction GHG emissions calculation included:

- Combustion of liquid fuels from:
  - Stationary and mobile plant equipment and other vehicles
  - International shipping from import of LRVs and steel rails
- Power consumption from the electrical grid
- Embodied energy of:
  - Construction materials
  - Construction and demolition waste
  - LRVs and batteries
- Vegetation clearing of urban street trees
- Replanting of street trees (carbon sink)

For operation the GHG emissions calculated included:

- Power consumption from the electrical grid both annually and over the asset life
- Maintenance activities over the asset life including:
  - Combustion of liquid fuels associated with:
    - Regular maintenance from street sweeping of light rails
    - Mobile equipment and international deliveries associated with major preventative maintenance activities.
  - Embodied energy associated with replacement of LRVs and lithium-ion batteries and key materials identified during construction.

As detailed design progresses, there may be adjustments to the types and quantities of inputs to the GHG assessment, with subsequent recalculation of GHG emissions undertaken.

The total emissions generated from construction by the Project were estimated to be 17,242t CO_2^{-e}, inclusive of Scopes 1, 2 and 3. The majority of the emissions are Scope 1 at 57% of the construction Project, which are emissions generated on site. Diesel fuelled mobile equipment has the highest contribution to Scope 1 emissions, followed closely by diesel fuelled lighting. Scope 2 emissions, which are due to electricity consumption from the grid equates to zero emissions due to the uptake of 100% renewable energy by ACT. Scope 3 emissions, which are emissions that are generated off site, however are directly related to the Project in terms of offsite transport or GHG generation during the manufacture of materials and supplies, account for 43% of the construction Project.

The construction of the Project is expected to represent approximately 0.0035% of Australia's total emissions and 1.6% of ACT's total emissions, however, these Project-related GHG emissions are likely to be offset by minimising increases in GHG emissions from other forms of transport such as private motor vehicles and buses. In addition all Project GHG emissions will be offset.

Estimation of annual operational GHG emissions have been limited to Scope 2 emissions from electricity consumption from lighting, signalling, bore pumping and battery charging of LRVs at stations. The total estimated annual electrical consumption from the Project per annum is 1,224,065 kWh; with the majority attributed to charging lithium-ion batteries. However, in the ACT electricity is 100% renewable and therefore Scope 2 emissions have a low CO_2^{-e} intensity; therefore, operational Scope 2 emissions from the Project are considered negligible.

GHG emissions from the Project from maintenance activities were estimated to be 7408 t CO_2^{-e} over an assumed asset life of 50 years. Approximately one third is attributed to Scope 1 emissions from fuel combustion; the remaining two thirds is Scope 3 emissions from fuel combustion associated with international imports and embodied energy in materials requiring replacement.

References

ACT Government (2017) *Past and Projected future components of electricity supply to the ACT, and resultant emissions intensity*. Australian Capital Territory Government, Environment and Planning Directorate, Climate Change, ACT, Canberra

ACT Government (2021) *ACT Government Greenhouse Gas Inventory for 2020-21,* Australian Capital Territory Government, Environment and Planning Directorate, Climate Change, ACT, Canberra

ARUP (2021) *Major Projects Canberra, Canberra Light Rail Stage 2, Traction Power Model*, Revision A, August 2021, Arup Pty Ltd, Sydney, NSW, Australia

Commonwealth of Australia (2021) National Greenhouse Accounts Factors, Australian National Greenhouse Accounts (August 2021), Australian Government, Department of Industry, Science, Energy and Resources

Han Hao *et al* (2017) *GHG Emissions from the Production of Lithium-Ion Batteries for Electric Vehicles in China*. Sustainability 2017 9(4) 504

Transport Authorities Greenhouse Group (TAGG) (2013); Greenhouse Gas Assessment Workbook for Road Projects

Transport for NSW (2017) *Carbon Estimate and Reporting Tool Manual,* Transport for NSW, NSW Government

Appendix A

Construction GHG emissions inventory calculation

1.0 Overview

The following appendix provides a summary of the equations used to estimate greenhouse gas (GHG) emissions from Project construction and includes assumptions regarding data inputs based on the design provided at Works Approval (WA)/Development Application (DA) lodgement. GHG emission sources for construction include:

- Combustion of liquid fuels from stationary and mobile plant equipment and other vehicles
- Power consumption from the electrical grid
- Embodied energy of:
  - Construction materials
  - Construction and demolition waste
  - Light rail vehicles (LRVs) and batteries
- Vegetation clearing of urban street trees
- Replanting of street trees (carbon sink).

The calculation methodology utilised to assess the GHG contribution of the Project is as outlined in the National Greenhouse and Energy Reporting Act 2007 and the accompanying National Greenhouse and Energy Reporting (Measurement) Determination 2008 (amended 1 July 2021).

Scope 1 emissions have been estimated using the default method (Method 1) using GHG emission factors listed in The National Greenhouse Accounts Factors, Australian National Greenhouse Accounts (Commonwealth of Australia 2021) (NGA) to assess the GHG contribution of the Project.

Calculation of Scope 2 emissions has incorporated an ACT specific emission factor for electricity consumption as published within the ACT Greenhouse Gas Inventory For 2020-21 (ACT, 2021). This accounts for the 100% reliance on renewable energy within the ACT as opposed to the NGA emission factor for ACT/NSW which is considerably higher to reflect the higher reliance on fossil fuels within the state of NSW.

In addition, the following guidelines and tools were used for the assessment[1]:

- TfNSW Carbon Estimate and Reporting Tool (TfNSW, 2017)
- Greenhouse Gas Assessment Workbook for Road Projects (TAGG, 2013).

[1] The National Greenhouse and Energy Reporting (Measurement) Determination 2008 deals with Scope 1 emissions and Scope 2 emissions. Supplementary Material in TAGG 2013 and CERT 2017 has been used for estimating Scope 3 emissions for the Project.

2.0 Scope 1 emissions

2.1 Fuel combustion

2.1.1 Methodology

Scope 1 emissions for fuels used for transport energy purpose were estimated using the following equation listed in Section 2.2 of the *National Greenhouse Accounts Factors* (2021)

$$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1000}$$

Where:

E_{ij}	=	Emissions of gas type (j) (CO_2, CH_4 or NO_x form fuel type in tonnes of CO_2-e
Q_i	=	Qi is the quantity of fuel type (i) (kilolitres or gigajoules) combusted for transport energy purposes
EC_i	=	ECi is the energy content factor of fuel type (i) (gigajoules per kilolitre or per cubic metre) used for transport energy purposes — see Table 4. If Qi is specified in gigajoules, then ECi is 1
EF_{ijoxec}	=	EFijoxec is the emission factor for each gas type (j) (which includes the effect of an oxidation factor) for fuel type (i) (kilograms CO_2-e per gigajoule) used for transport energy purposes

All Scope 1 GHG emissions from fuel combustion were estimated using emission factors for general transport using diesel oil listed under Table 4 of the *National Greenhouse Accounts Factors* (2021). An emission factor of 70.2 CO_2-e/Gigajoules (GJ) was used based on the combined emission factors for diesel oil for CO_2, CH_4 and N_2O. An energy content factor for diesel oil of 38.6 GJ/kL was adopted in accordance with Table 4 of the *National Greenhouse Accounts Factors* (2021).

Estimated fuel quantities for each source are provided in **Section 2.1.2.** A detailed emissions inventory for Scope 1 construction emissions is also provided in **Section 2.1.3**.

2.1.2 Quantity estimations

The following subsections provide a detailed description of fuel quantity estimations from key sources of fuel combustion during construction.

2.1.2.1 Diesel generators

Estimated diesel fuel consumption from generators for individual construction activities are provided in **Table 1**. Fuel consumption for all construction activities has been based on the use of 30kVa diesel generators with a fuel consumption rate of 7.7L per hour at 100% prime load.

All generators were assumed to be operational six days per week over a 12-hour period with a 90% utilisation factor; with exception to the 56-hour shutdown periods for works required at intersections, where 100% utilisation has been assumed. Program weeks were derived from the construction program.

Table 1 Estimated diesel fuel quality from generators for all construction activities

Construction activity	No. generators	Operational hours (h/week)	Utilisation (%)	Qty (L/week)	Program (weeks)	Total fuel Qty (kL)
Parkes Way bridge	1	72	90	499	65	33
Utilities	2	72	90	998	135	134
Edinburgh Ave Stop	1	72	90	499	83	41
City South Stop	1	72	90	499	56	28
Commonwealth Park Stop	1	72	90	499	61	30
Intersections 56hr Shutdowns	1	56	100	431	130	56
Intersections longer duration locations	1	72	90	499	83	41

Construction activity	No. generators	Operational hours (h/week)	Utilisation (%)	Qty (L/week)	Program (weeks)	Total fuel Qty (kL)
Block closures (Civil & Track)	2	72	90	998	83	82
CSR works, HV/LV cable pull & terminations	1	72	90	175	39	7
Testing & commissioning	1	72	90	175	39	7
					Total fuel quantity (kL)	**460**

2.1.2.2 Mobile equipment

Mobile plant equipment numbers were derived from the plant resources summary for the Project. The plant resources summary provides the total number of days construction equipment is required in a month irrespective of the number of mobile equipment used on a given day[2].

For key mobile equipment, the days per month required from the plant resources summary was used to calculate the equipment utilisation rate per month[3]. The equipment utilisation per month was then summed together for each item to estimate the total utilisation rate in months over the duration of the construction program. A summary of the total utilisation rate in months for each key mobile equipment type is provided in **Table 2**.

Table 2 also provided the total diesel fuel consumption per mobile equipment type with default fuel consumption rates derived from Table 5-5 in TAGG 2013. Monthly fuel consumption rates in TAGG2013 are considered conservative and assume a total of 300 operational hours per month.

Table 2 Estimated diesel fuel quality from mobile equipment for all construction activities

Mobile equipment	Utilisation (months)	Fuel consumption rate (kL/month)	Total fuel Qty (kL)
12T Excavator	61.0	5.1	311
20T Excavator	97.7	5.1	498
32T Excavator	6.0	5.1	31
6T Dumper	12.0	7.9	95
Front End Loader	69.0	4.5	311
Low Loader	11.2	4.5	50
Backhoes	41.3	3.0	124
Grader	10.0	5.1	51
Rollers	29.3	4.8	141
Paver	2.2	7.1	15
Small mobile cranes	0.6	7.9	5
Large mobile cranes	0.2	110.6	18
Franna crane	9.2	7.9	73
Cherry picker	1.0	1.6	2
Compressor	48.0	2.3	110
Piling rig	0.3	7.9	2
Scissor lift	6.7	1.6	11

[2] Where the number of days was greater than 30 this was indicative of multiple pieces of equipment utilised throughout the month.
[3] Here where the equipment utilisation rate was greater than 1.0 it is assumed that more than one piece of equipment is utilised throughout the month.

Mobile equipment	Utilisation (months)	Fuel consumption rate (kL/month)	Total fuel Qty (kL)
		Total fuel quantity (kL)	**1,890**

2.1.2.3 Lighting

Estimated diesel fuel consumption for individual construction activities requiring temporary lighting towers are provided in **Table 3**. Portable lighting towers were assumed to have a fuel tank capacity of 130L with a consumption rate of 2.25L/h. Lighting towers were assumed to operate for 12 hours per day seven days per week. Program weeks were derived from the construction program.

Table 3 Estimated diesel fuel quality from temporary lighting for all construction activities

Construction activity	No. lighting towers	Operational hours (h/week)	Qty (L/week)	Program (weeks)	Total fuel Qty (kL)
Parkes Way bridge	4	84	756	65	49
Parkes Way bridge (Contraflow Program)	33	84	6,300	26	164
Utilities	4	84	756	135	102
Edinburgh Ave Stop	4	84	756	83	62
City South Stop	4	84	756	56	43
Commonwealth Park Stop	4	84	756	61	46
Intersections 56hr Shutdowns	8	84	1,008	130	131
Intersections longer duration locations	8	84	1,512	83	125
Block closures (Civil & Track)	8	84	1,512	83	125
				Total fuel Quantity (kL)	**847**

2.1.2.4 Onsite light vehicles

Site vehicles have been divided into three main categories, employee vehicles driving to and from site compounds, site vehicles used for construction work and traffic control and are discussed below.

Compounds

Onsite light vehicle numbers have been derived based on 50% capacity of the construction compounds: equating to 117 vehicles per day, six days per week. Light vehicles onsite would largely be related to employees driving to site; with vehicles expected to remain parked at site compounds for the duration of the working day, before leaving the site with an estimated 1.4km travel distance assumed within the construction footprint per trip. Emissions from light vehicles travelling to and from the construction footprint have been estimated as Scope 3 emissions in **Section 4.1**.

For conservatism all light vehicles were assumed to be diesel operated light commercial vehicles with a fuel consumption rate of $1.22x10^{-4}$ kL/km adopted from Table 5-4 in TAGG 2013. Based on the above assumptions a total of 149,459 vehicle kilometres travelled (VKT) were assumed based on a 35 construction program commencing in early 2024 with construction completion planned in 2026, equating to 18.23kL of diesel fuel consumed.

Construction activities

Assumed numbers for onsite construction vehicles for construction activities are provided in **Table 4**. Fuel consumption rates were scaled from the TAGG 2013 monthly diesel fuel default factor for site vehicles for large projects which assumes 0.34kLper Hilux Ute. Total fuel consumption for each activity were based on the construction program.

Table 4 Estimated diesel fuel quality from onsite light vehicles for construction activities

Construction activity	No. vehicles	Program (months)	Total fuel Qty (kL)
Parkes Way bridge	8	15	41
Utilties Works	8	31	84
Edinburgh Ave Stop	6	19	39
City South Stop	6	13	27
Commonwealth Park Stop	6	14	29
Intersection Works (56hr & Long term)	10	30	102
Block closures	10	19	65
CSR works, HV/LV cable pull & terminations	6	9	18
Testing & commissioning	8	9	24
		Total fuel Quantity (kL)	**428**

Traffic control

A total of 10 traffic control vehicles were assumed to be present onsite for the duration of the construction program expected to commence in early 2024 and be completed by late 2026. A diesel fuel consumption rate of 0.34kL/month per vehicle from the Table 5-3 TAGG 2013 default factor for site vehicles; a 10% utilisation factor was also assumed as traffic management vehicles. The total fuel consumption for traffic control vehicles was estimated at 11.9kL.

2.1.2.5 Onsite deliveries

Onsight delivery numbers have been derived from Project plant take off estimates and are summarised in **Table 5.** Onsight haul routes for deliveries were assumed to be 1.4km per trip. Emissions from deliveries travelling to and from the construction footprint have been estimated as Scope 3 emissions in **Section 4.1**.

Table 5 Estimated delivery traffic volumes

Activity	Vehicle numbers					Total
	Truck & Dog	Concrete	Semitrailer	Rigid Truck	Tipper	
Import	2,496	1,968	128	147	354	5094

From Table 5-4 in TAGG 2013 a default diesel fuel consumption rate of 5.6x10-4 kL/km for large trucks was assumed. Based on 5,094 deliveries the total VKT of 7,132 was estimated from deliveries: and a total fuel consumption of 3.99kL.

2.1.2.6 Onsite waste transport

Onsite vehicle numbers for transport of construction waste have been derived from Project plant take off estimates summarised in **Table 6.** In addition to construction waste in **Table 6**, an additional two trips per week over the duration of the construction program were assumed (one recycling and one general waste) to service the construction compounds.

Table 6 **Estimated onsite construction waste transport traffic volumes**

Activity	Vehicle numbers				Total
	Truck & Dog	Semitrailer	Rigid Truck	Tipper	
Construction waste export	2598	3	28	142	2771

Onsight haul routes for all waste exports were assumed to be 1.4km per trip. Emissions from deliveries travelling to and from the construction footprint have been estimated as Scope 3 emissions in **Section 4.1**. From Table 5-4 in TAGG 2013 a default diesel fuel consumption rate of 5.6x10-4 kL/km for large trucks was assumed. Total fuel consumption rates are provided in **Table 7**

Table 7 **Estimated diesel fuel consumption for waste transport**

Waste transport activity	No vehicles	VKT	Total fuel Qty (kL)
Construction material	2,771	3,880	2.17
Waste from compounds	304	426	0.24
		Total fuel Quantity (kL)	**2.41**

2.1.3 Detailed emissions inventory

A detailed emissions inventory breakdown for fuel sources is provided in **Table 8**.

Table 8 **Detailed emissions inventory for Scope 1 diesel fuel consumption**

Activity	Sub-activity	Fuel Qty (kL)	GHG emissions (CO_2-e)
Diesel Generators	Parkes Way bridge	33	88
	Utilities	134	364
	Edinburgh Ave Stop	41	112
	City South Stop	28	76
	Commonwealth Park Stop	30	82
	Intersections 56hr shutdowns	56	152
	Intersections longer duration locations	41	112
	Block closures (Civil & Track)	82	223
	CSR Works, HV/LV cable pull & terminations	7	19
	Testing & commissioning	7	19
Mobile equipment	12T Excavator	311	1,351
	20T Excavator	498	83
	32T Excavator	31	257
	6T Dumper	95	842
	Front End Loader	311	137
	Low Loader	50	336
	Backhoes	124	138
	Grader	51	382
	Rollers	141	42
	Paver	15	1,351

Activity	Sub-activity	Fuel Qty (kL)	GHG emissions (CO_2-e)
	Small mobile cranes	15	14
	Large mobile cranes	5	51
	Franna crane	18	205
	Cherry picker	73	5
	Compressor	2	320
	Piling rig	110	7
	Scissor lift	2	32
Lighting	Parkes Way bridge	49	134
	Parkes Way bridge (Contraflow Program)	164	455
	Utilities	102	276
	Edinburgh Ave Stop	62	169
	City South Stop	43	116
	Commonwealth Park Stop	46	125
	Intersections 56hr shutdowns	131	356
	Intersections longer duration locations	125	338
	Block closures (Civil & Track)	125	338
Site vehicles (compounds)	Compounds	18.23	49
Site vehicles (constructions)	Parkes Way bridge	41	111
	Utilities Works	84	228
	Edinburgh Ave Stop	39	105
	City South Stop	27	72
	Commonwealth Park Stop	29	77
	Intersection Works (56hr & Long term)	102	276
	Block closures	65	175
	CSR Works, HV/LV cable pull & terminations	18	50
	Testing & commissioning	24	66
Site vehicles (Traffic control)	Traffic Control	11.9	32
Deliveries (onsite)	All deliveries	3.99	10.8
Waste transport	Construction material	2.17	5.9
	Waste from compounds	0.24	0.6

2.2 Vegetation

2.2.1 Methodology

Removal of urban vegetation through loss of carbon sink has been calculated using the methodology for removal of urban street trees in CERT 2017. Similarly planting of new trees associated with the Project has been used to calculate the introduction of new carbon sinks as part of the Project using the CERT 2017 methodology. Assumed emission factors are provided in **Table 9**, with all trees estimated to be of medium size.

Table 9 CO_2 sequestered per tree

Tree size	Kg CO_2 sequestered/tree
Medium	1550

In addition to urban tree removal the amount of CO_2 sequestered in landscaped areas (ground cover) and green track areas were estimated for the Project. This was estimated using TAGG 2013 methodology. A Vegetation Class of I (Grassland) was adopted for all landscaping and green track areas using a biomass class value of 2 for the ACT region. Based on the Vegetation Class and Max Biomass Class a GHG emission factor of 110t CO_2^{-e}/ha was adopted at each site.

2.2.2 Quantity estimation

Estimated tree removal and street tree plantings numbers have been obtained from the plant take of information for the Project. Established trees are expected to be planted as part of landscaping works and have been assumed to be moderate in size. The number of trees removed and planted are provided in **Table 10**. Assumed surface areas for establishment of green track and ground cover areas are also provided in the **Table 11** and have been taken from plant take of information for the Project.

Table 10 Estimated tree removal and planting numbers

Activity	Tree size	No. trees
Tree removal (Loss of carbon sink)	Medium	100
Tree planting (Introduction of carbon sink)	Medium	145

Table 11 Estimated area of green track and landscaping

Activity	Area (ha)
Green track construction	0.51
Ground cover	0.10

2.2.3 Detailed emissions inventory

A detailed emissions inventory for vegetation is provided in **Table 12**. Here CO_2 sequestration from street planting, the green track and ground cover as part of the Project is subtracted from the loss of carbon sink from urban tree removal during construction. The total provided the net Scope 1 CO_2 emissions from construction of the Project. As the net GHG emissions is negative, indicates the introduction of new carbon sinks more than offsets the loss of carbon sinks from vegetation removal associated with the Project.

Table 12 Detained emissions inventory for Scope 1 vegetation emissions from construction

Sequestration category	Activity	Sub-activity	Qty	Units	GHG emissions (t CO_2-e)
Loss of carbon sink	Tree removal	Medium tree	100	No. trees	155.0
Introduction of carbon sink	Tree planting	Medium tree	145	No. trees	-224.8
	Track	Green track	0.51	ha	-55.6
	Landscaping	Ground cover	0.10	ha	-10.7
				Net GHG emissions	**-136**

3.0 Scope 2 emissions

3.1 Methodology

Scope 2 emissions for fuels used for transport energy purpose were estimated using the following equation listed in Section 2.3 of the *National Greenhouse Accounts Factors* (2021)

$$Y = Q \times \frac{EF}{1000}$$

Where:

Y	=	Scope 2 emissions measured in CO_2^{-e} tonnes
Q	=	Quantity of electricity purchased (kilowatt hours)
EF	=	Emission factor, for the State, Territory, or electricity grid in which the consumption occurs (kg CO_2^{-e} per kilowatt hour)

Table 5 the NGAF 2021 lists Scope 2 emission factor for electricity usage in NSW and ACT as 0.79kg CO_2^{-e}/kWh. The NGA emission factor for the Project of 0.79 kg CO_2^{-e}/kWh is considered overly conservative for ACT given NSW's high dependence on fossil fuels. The ACT Greenhouse Gas Inventory For 2020-21 (ACT, 2021) reported ACT as having sourced 100% renewable energy, and therefore a zero emission factor was adopted. This is considered appropriate for future years also due to the ACT's ongoing commitment to renewing offset emissions through the use of Large Generation Certificates (LGC's).

Given the ACT achieved its goal to source 100% of its electricity from renewable generators in 2020 this value is considered more representative emission factor to estimate potential construction impacts from the Project.

As such an emission factor of 0kg CO_2^{-e}/MWh for the 2020-2021 financial year has been reported for operational impacts; noting electrical consumption is still shown for transparency.

3.2 Quantity estimation

Estimation of electricity usage during construction would primarily be attributed to the use of four construction compounds continuously over the 2024-2026 construction period. Operation of construction compounds included electrical consumption for a range of appliances including:

- Building lighting
- Security, flood lighting & CCTV
- Televisions
- Laptop and monitors
- Amenities and hot water
- Ventilation/air-conditioning
- Printers
- Dishwasher
- Fridges
- Small kitchen appliances.

A summary of electricity consumption is provided in **Table 13**.

Table 13 Electrical consumption

Area	Weekly electricity usage (kWh/week)	Weeks	Total electricity usage (kWh)
Compound 1 (Marcus Clarke Street)	17,532	152.1	2,666,163
Compound 2 (Vernon Cct Carpark)	13,647	152.1	2,075,435
Compound 3 (Commonwealth Park)	18,832	152.1	2,863,831
Compound 4 (Parkes Way/SW Cloverfield)	10,120	152.1	1,538,962
		Total kWh	9,144,392

3.3 Detailed emissions inventory

The Scope 2 emission factor for electricity consumption in the ACT is negligible due to the use of 100% renewable energy. Therefore, GHG emissions from electricity usage during construction of the Project are considered negligible.

4.0 Scope 3 emissions

4.1 Fuel consumption

4.1.1 Methodology

Scope 3 emissions for fuels used for domestic transport energy purposes were estimated using the following equation listed in Section 2.2 of the *National Greenhouse Accounts Factors* (2021)

$$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1000}$$

Where:

E_{ij}	=	Emissions of gas type (j) (CO_2, CH_4 or NO_x form fuel type in CO_2^{-e} tonnes
Q_i	=	Qi is the quantity of fuel type (i) (kilolitres or gigajoules) combusted for transport energy purposes
EC_i	=	ECi is the energy content factor of fuel type (i) (gigajoules per kilolitre or per cubic metre) used for transport energy purposes — see Table 4. If Qi is specified in gigajoules, then ECi is 1
EF_{ijoxec}	=	EFijoxec is the emission factor for each gas type (j) (which includes the effect of an oxidation factor) for fuel type (i) (kilograms CO_2^{-e} per gigajoule) used for transport energy purposes.

All GHG emissions for Scope 3 emissions from domestic vehicles was estimated using the emission factors for general transport using diesel oil listed under Table 4 of the *National Greenhouse Accounts Factors* (2021). An emission factor of 70.2 CO_2^{-e}/GJ was used based on the combined emission factors for diesel oil for CO_2, CH_4 and N_2O. An energy content factor for diesel oil of 38.6 GJ/kL was adopted in accordance with Table 4 of the *National Greenhouse Accounts Factors* (2021).

Domestic transport includes delivery vehicles, waste transport and light vehicles and estimated fuel quantities for each source are provided in **Section 4.1.2.**

International deliveries for LRV's from Spain and rail steel for Austria have also been accounted for, including GHG emission estimates from shipping and road transport. The emission factor for shipping of 0.00893 kg CO_2^{-e}/tkm (tonnes. Kilometres) has been adopted from CERT and is based on emissions from a transoceanic freight ship. Similarly, from CERT 2018 an emission factor of 0.0726 kg CO_2^{-e}/tkm has been adopted for road transport and is based on an articulated truck with an 28t capacity. Transport activity values in tkm for import of LRVs and rail steel are also provided in **Section 4.1.2.**

A detailed emissions inventory for Scope 1 construction emissions is also provided in **Section 4.1.3**.

4.1.2 Quantity estimations

The following subsections provide a detailed description of fuel quantity estimations from key sources of fuel combustion during construction for domestic operations including material deliveries, waste transport and light vehicles. Transport activity values for international shipping and road transport are also discussed in this section.

4.1.2.1 Deliveries

Delivery numbers have been derived from Project plant take off estimates summarised in **Table 14.**

Table 14 Estimated delivery traffic volumes

Activity	Vehicle numbers					Total
	Truck & Dog	Concrete	Semitrailer	Rigid Truck	Tipper	
Import	2496	1968	128	147	354	5,094

Estimated haul routes for deliveries and fuel consumption rates are provided in **Table 15**. Concrete deliveries were assumed to be from Fyshwick, ACT; approximately 8.4km to London Circuit. Steel deliveries were assumed to be from Mitchell, ACT approximately 9km to London Circuit[4]; and all other deliveries were estimated to occur within 40km (one way) of the Project site.

The number of concrete deliveries was obtained from the plant take off estimates for the Project as shown in **Table 14**. Three steel deliveries for every seven concrete deliveries were assumed for the Project in line with peak vehicle movements from the Project: with the remaining number of deliveries in **Table 14** accounting for all other deliveries.

Fuel quantities in **Table 15** were calculated using the default diesel fuel consumption rate of 5.6x10-4 kL/km for large trucks in Table 5-4 of TAGG 2013.

Table 15 Assumed haul routes for deliveries and estimated diesel fuel consumption

Delivery	Total deliveries	Haul route -round trip (km)	VKT	Total fuel Qty (kL)
Concrete	1,968	16.8	33,064	18.5
Steel	591	18.0	10,638	5.96
Other deliveries	2,535	80.0	202,797	114
			Total fuel Qty (kL)	138

4.1.2.2 Waste transport

Vehicle numbers for transport of construction waste have been derived from Project plant take off estimates and are summarised in **Table 16.** In addition to construction waste in **Table 16** an additional two trips per week over the 2024-2026 construction period were assumed (one recycling and one general waste) to service the construction compounds.

Table 16 Estimated construction waste transport traffic volumes

Activity	Vehicle numbers				Total
	Truck & Dog	Semitrailer	Rigid Truck	Tipper	
Construction waste export	2,598	3	28	142	2,771

Estimated haul routes for deliveries and fuel consumption rates are provided in **Table 17.** The bulk of excess spoil and construction waste is expected to be exported offsite to the West Belconnen Resource Management Centre approximately 3km from the site (one way trip) Fuel quantities in **Table 17** were calculated using the default diesel fuel consumption rate of 5.6x10-4 kL/km for large trucks in Table 5-4 of TAGG 2013.

Table 17 Estimated diesel fuel consumption for waste transport

Waste transport activity	Total exports	Haul route -round trip (km)	VKT	Total fuel Qty (kL)
Construction material	2771	6.0	16627	9.3
Waste from compounds	304	6.0	1825	1.0
		Total fuel quantity (kL)	**2.47**	**10.3**

4.1.2.3 Light vehicles

An estimate of employee light vehicles traveling to and from work for construction has been estimated for the Project. Light vehicle numbers have been derived based on 50% capacity of the construction

[4] Rail steel for the Project would be imported from Austria and has been omitted from GHG estimations. Embodied energy from internationally source rail steel however has been included in the GHG inventory in Section 4.3 below.

compounds: equating to 117 vehicles per day, six days per week. Light vehicles were estimated to travel to work within a 20km radius of the site (one way).

For conservatism all light vehicles were assumed to be diesel operated light commercial vehicles with a fuel consumption rate of 1.22×10^{-4} kL/km adopted from Table 5-4 in TAGG 2013. Based on the above assumptions a total of 42,70,266 VKT were assumed based on the 2024-2026 construction period equating to 521kL of diesel fuel consumed.

4.1.2.4 International Imports

Greenhouse gas emission estimates for international imports are based on the mass of material (in tonnes) and the distance travelled (in kilometres). The mass of steel from the LRV's and rails was estimated at 208t and 340.9t respectively and is discussed in more detail in Section 4.3.2. Estimated travel distances included both shipping and road transport as modes of travel.

The LRV's are to be imported from Spain; and an estimated one way travel distance of 15,965 km[5] for freight shipping was estimated for a transoceanic freight ship between the Port of Valencia, Spain and Port Kembla, Australia. Rail steel would be imported from Austria, and was assumed to travel by road from Donawitz, Austria to the Port of Venice in Italy with an estimated one way shipping distance of 15,389 km.

Based on the estimated steel mass and shipping distances discussed above, quantities of 3,322,642 tkm and 5,245,709 tkm were used to estimate shipping emissions from LRVs and rail steel respectively.

Emissions from road transport was also included for port transfers between Port Kembla and the project site for LRV and rail steel deliveries and from Austria to the Port of Venice Italy for rail steel. One-way distances from Austria to Italy and for domestic port transfers were estimated at 423km and 252 km respectively. Total VKT travelled for each activity were calculated based on one-way distances for an articulated truck with a 28t capacity operating; with a carrying capacity of 80% applied; equating to 22.4t per trip. Rounded up to the nearest whole value approximately 10 trips would be required for LRV deliveries and 16 trips per road transport activity for the delivery of rail steel.

Using the estimated load per trip of 22.4t and VKT per activity an activity value of 151,603 tkm was estimated or the transport of road steel from Austria to Italy and 56,448 tkm (LRVs) and 90,317 tkm (rail steel) for domestic port transfers.

Assumed values used to estimate the total tkm for international shipping and road transport activities are provided in **Table 18**.

Table 18 Estimated activity values for international import of materials

Category	Activity	Haul Route (one way) (km)	Steel Qty (t)	VKT (km)	Transport Activity (tkm)	Total Qty (tkm)
Shipping	LRVs (Spain)	15,965	208.1	-	3,322,643	8,568,352
	Rail steel (Italy)	15,389	340.9	-	5,245,709	
Road Transport	Rail steel port transfer (Austria)	423	340.9	6,768	151,603	298,368
	LVRs domestic port transfers	252	208.1	2,520	56,448	
	Rail steel domestic port transfers	252	340.9	4,032	90,317	

[5] Estimated shipping distances were calculated using httpe://sea-distaces.org and assumed that LVRs would travel from the Port of Valencia. Spain to Port Kembla, Australia and for Rail Steel from Venice, Italy to Port Kembla, both via the SueZ Canal.

4.1.3 Detailed emissions inventory

A detailed emissions inventory breakdown for fuel sources is provided in **Table 19**.

Table 19 Detailed emissions inventory for Scope 3 fuel consumption

Activity	Sub-activity	Qty	Unit	GHG emissions (CO_2-e)
Domestic Deliveries	Concrete	18.5	kL	2.6
	Steel	6.0	kL	0.8
	Other deliveries	113.6	kL	15.8
International Imports	Shipping	8,568,352	tkm	76.5
	Road transport	298,368	tkm	21.7
Waste transport	Construction material	9.3	kL	1.3
	Waste from compounds	1.0	kL	0.1
Light vehicles	Light commercial	521.0	kL	72.4
Total GHG emissions (t CO_2-e)				**191.2**

4.2 Waste

4.2.1 Methodology

Scope 3 emissions from construction material (embodied energy) has been calculated using the construction material emission factors published in the *National Greenhouse Accounts Factors* (2021). GHG emissions from waste was estimated using the following equation

$$Y = Q \times EF$$

Where:

Y	=	Scope 3 emissions measured in CO_2-et
Q_i	=	Quantity of waste material in tonnes
EF	=	Emission factor of waste material in t/CO_2-e/t

Inert waste material from the Project in accordance with NGAF 2021 methodology such as spoil from earthworks and concrete and pavement waste are assumed to have an emission factor of 0 t CO_2-e/t of waste material but have been provided for transparency. All other general construction waste from the Project was assumed to have an emission factor of 0.2 t CO_2-e/t as defined as construction and demolition waste in NGAF 2021.

4.2.2 Quantity Estimations

Waste material quantities have been estimated from the plant take off information for the Project and are summarised in **Table 20**.

Table 20 Estimated diesel fuel consumption for waste transport

Waste Type	Qty (t)
Earthworks	46,745
General solid waste (GSW)	5,530
Other inert material	29,335

4.2.3 Detailed Emissions Inventory

A detailed emissions inventory for waste material from the Project is provided in **Table 21**.

Table 21 Detailed emissions inventory for Scope 3 diesel fuel consumption

Waste material	Qty (t)	Emission factor (t CO_2-e/t)	GHG emissions (t CO_2-e)
Earthworks	46,745	0	0
GSW	5,530	0.2	1,106
Other inert material	29,335	0	0
		Total GHG emissions (t CO_2-e)	**1,106**

4.3 Embodied energy

4.3.1 Methodology

Scope 3 emissions from the embodied energy of construction materials was estimated using the following equation

$$Y = Q \times EF$$

Where:

Y	=	Scope 3 emissions measured in CO_2-e t
Q_i	=	Quantity of construction material per unit of measure (UoM) in tonnes of cubic metres or capacity of the battery in kilowatt hours
EF	=	Emission factor of construction material in kgCO_2-e/ UoM or tCO_2-e/kWh

Emission factors for embodied energy of construction materials and reference sources are supplied in **Table 22**.

Table 22 Emission factors for embodied energy in construction materials

Material	Assumed classification	Emission factor	Reference
LRV	Structural steel beams (imported)	3,000 kgCO_2e-/t	CERT 2017
LRV Batteries	Average emission factor for LFP batteries	135.7 kgCO_2e-/kWh	Haao *et. al* 2017
Asphalt	Hot mix asphalt with 0% RAP	65kgCO_2e-/t	CERT 2017
Glass	Glass	1,095kgCO_2e-/t	CERT 2017
Sand	Sand	4.3kgCO_2e-/t	CERT 2017
Pavement	Stone pavement (granite)	93kgCO_2e-/t	Hammond & Jones 2008
	Brick pavement	0.38tCO_2e-/t	TAGG 2013
	Precast concrete 40 MPa pavement	398kgCO_2e-/t	CERT 2017
Drainage	Reinforced concrete pipe	280kgCO_2e-/t	CERT 2017
Steel	Parkes Way bridge (Structural)- Structural steel beams and columns (Australian product)	2,900kgCO_2e-/t	CERT 2017
	Parkes Way bridge (finishing works) Structural steel plate (Australian product)	2,800kgCO_2e-/t	CERT 2017
	Steel rails (imported products)	3,400kgCO_2e-/t	CERT 2017
Concrete	Poured concrete (40MPa)	0.155tCO_2e-/t	TAGG 2013
	Precast concrete (40MPa)	398 kg CO_2e-/m^3	CERT 2017

4.3.2 Quantity Estimations

4.3.2.1 Light rail vehicles

Embodied energy calculation for LRVs has been limited to steel within each of the five new LRVs and batteries for the new LRVs and 14 retrofitted LRVs from Stage 1 of the Project.

Steel weight of each LRV is assumed to be equal to the tare load of each vehicle prior to being fitted with batteries. The tare load of each vehicle was assumed to be 41.625t which equates to a total of 208t, based on the addition of five new LRVs.

Each of the five new LRVs and 14 existing LRV vehicles will be fitted with two modules, each containing three batteries. The batteries are lithium ferrophoshate and collectively hold 136.08kWh in total for each LRV; with a combine total of 2,585.52kWh.

4.3.2.2 Asphalt

Asphalt quantities have been obtained from plant take off information for the Project and are summarised in **Table 23.** A density of 2.4 t/m^3 for asphalt has been sourced from CERT 2017.

Table 23 Assumed asphalt quantities

Activity	Qty (t)	Qty (m^3)
New pavements and roads (PT1)	341	142
New pavements and roads (PT2)	2,358	983
New pavements and roads (pt3) partial reconstruction	932	388
New pavements and roads (pt4) asphalt mill and resheet	1,068	445
New pavements and roads (PT6a) Conc driveway/bikepath with asphalt	11	5
New pavements and roads (PT10) Asphalt carpark & bikepath	39	16
New pavements and roads (PT11a) Conc pavement with asphalt surface	150	63

4.3.2.3 Glass

Glass quantities have been obtained from plant take off information for the Project and are summarised in **Table 23.** A density of 2500kg/m^3 for glass has been sourced from the CERT 2017 document; and a thickness of 10mm was assumed for all glazed weather screens.

Table 24 Assumed asphalt quantities

Activity	Sub-activity	Qty (m^2)	Qty (t)
Edinburgh Ave Stop	Glazed weather screens	54	341
City South Stop	Glazed weather screens	26	2,358
Commonwealth Park Stop	Glazed weather screens	26	932

4.3.2.4 Sand

Sand quantities required for backfilling utility service trenches with cement stabilised sand are presented in **Table 25** and have been obtained from plant take off information for the Project. Sand was assumed to have a density of 1.6tm^3 from the CERT 2017 document.

Table 25 Assumed sand quantities

Activity	Sub-activity	Qty (m^3)	Qty (t)
Combined services route	Backfilling	440.6	705
New telecommunications	Backfilling		24

4.3.2.5 Pavement

Pavements have been categorised into three types for the Project, stone, brick, and cement for all finished surface treatments and are presented in **Table 26**. A concrete paver depth of 80mm was used based on Ecotrihex product information to determine the paver volume.

Table 26 Assumed pavement quantities

Pavements	Type	Area (m^2)	Qty
Stone	Paver Granite Paving "Austral Black"	6,081	866t
	Cobble Granite Cobble Setts "Austral Black", exfoliated finish driveway crossovers within public domain footpaths	46	
	Cobble Granite Cobble Setts "Austral Black", exfoliated finish pedestrian crossing within roadway	1,961	
	Paver Granite Paving to match existing "Austral Black"	227	
	Paver Granite Paving Juparana, exfoliated finish	433	
	Paver Granite Paving Austral "Verge", exfoliated finish	0	
	Paver Granite Paving (Banding) "Austral Verge", exfoliated finish	375	
	Paver Granite Paving "Austral Verge", exfoliated finish	329	
	Bluestone Paver with permeable flexible rubber/ Gravel Infill	1,439	
	Bluestone Segmented Paver	1,251	
	Bluestone Segmented Paver	204	
	Bluestone Segmented Paver (Header Course)	37	
	White Limestone Paving (Banding)	144	
	Heritage Cobble Stone Banding	42	
	Porphyry Cobble Stone Split Face Finish	6,601	
	Cobble Granite Cobble Setts "Austral Black"	45	
	Porphyry Cobble Stone Exfoliated Finish	123	
	Granite Paving "Harcourt White" with Flexible Polyurethane Rubber/ Grave Mix Permeable Pavement	30	
Brick	Brick Paving to match existing pavements	112	6.3t
Cement	Permeable Pavement Paver, Ecotrihex Concrete	405	$32m^3$

4.3.2.6 Drainage

Drainage quantities were estimated for reinforced concrete pipes only and were based on material quantities from plant take off information for the Project. Quantities are provided in **Table 27**.

Table 27 Assumed concrete reinforced pipe

Activity	Length (m)	Qty (t)
Rail drainage	60	7.6

Activity	Length (m)	Qty (t)
300mm dia. reinforced concrete pipe	155	27.8
375mm dia. reinforced concrete pipe	587	138.5
450mm dia. reinforced concrete pipe	422	123.1
525mm dia. reinforced concrete pipe	228	88.8
600mm dia. reinforced concrete pipe	441	219.6
675mm dia. reinforced concrete pipe	153	111.3
750mm dia. reinforced concrete pipe	103	88.9
800mm dia. reinforced concrete pipe	3	2.4
900mm dia. reinforced concrete pipe	263	216.4
100mm dia. CSR drainage pipe	375	22.1
100mm dia. Minor drainage pipe	238	14.0
1500x900 Attenuation culvert storage	176	364.3

4.3.2.7 Steel

Steel quantities for the Project have been estimated for the Parkes Way bridge and track rails only. Steel associated with the LRVs has been estimated separately in **Section 4.3.2.1**. The mass of steel rails was assumed to be 51.4kg/m and has been estimated on two rails at 3,316 track metres. Steel quantities are provided in **Table 28**.

Table 28 Assumed steel quantities

Activity	Sub-activity	Qty (t)
Parkes Way bridge	Bridge structure	190
	Finishing and associated works:	11.1
Trackwork	Track rails	340.9

4.3.2.8 Concrete

Concert volumes for the Project have been estimated from plant take off information for the Project and are summarised in **Table 29**.

Table 29 Assumed concrete quantities

Activity	Sub-activity	Qty
Poured concrete	Edinburgh Ave Stop (side platforms)	650t
	City South Stop (island platform)	233t
	Commonwealth Park Stop (island platform)	302t
	Pavements	5,754t
	Kerbing	2,262t
	Drainage sumps	599t
	Street lighting foundation	142t
	Parkes Way bridge	925t
	Trackforms and sleepers	4,100t
	Bridge deck	283t
	Utilities	1,165t
Precast	Edinburgh Stop (side platforms)	37.3 m^3

Activity	Sub-activity	Qty
	City South Stop (island platform)	19.2 m^3
	Commonwealth Park Stop (island platform)	22.2 m^3

4.3.3 Detailed Emissions Inventory

A detailed emissions inventory breakdown for embodied energy sources is provided in **Table 30**.

Table 30 Detailed emissions inventory for Scope 1 diesel fuel consumption

Activity	Sub-activity	Qty	Units	GHG emissions (t CO_2-e)
LRVs	LRV (Steel body)	208	tonnes	624
	LRV (LFP Batteries)	2,586	kWh	351
Asphalt	New pavements and roads (PT1)	341	tonnes	22.2
	New pavements and roads (PT2)	2,358	tonnes	153.3
	New pavements and roads (PT3) Partial reconstruction	932	tonnes	60.6
	New pavements and roads (PT4) Asphalt mill and resheet	1,068	tonnes	69.4
	New pavements and roads (PT6a) Conc driveway/bikepath with asphalt	11	tonnes	0.7
	New pavements and roads (PT10) Asphalt carpark & bikepath	39	tonnes	2.5
	New pavements and roads (PT11a) Conc pavement with asphalt surface	150	tonnes	9.8
Glass	Edinburgh Ave Stop - glazed weather screens	1.35	tonnes	1.5
	Edinburgh Ave Stop - glazed weather screens	0.65	tonnes	0.7
	Edinburgh Ave Stop - glazed weather screens	0.65	tonnes	0.7
Sand	Combined services route	705	tonnes	3.0
	New telecommunications	24	tonnes	0.1
Pavement	Stone pavement	866	tonnes	81
	Brick pavement	6	tonnes	2
	Concrete pavement	32	m^3	13
Drainage	Concrete reinforced pipes	1,425	tonnes	399
Steel	Parkes Way bridge - finishing works	190	tonnes	551.0
	Parkes Way bridge - structure	11.1	tonnes	31.1
	Rail tracks	341	tonnes	1159.0
Ready mix concrete	Edinburgh Ave Stop (side platforms)	650	tonnes	101
	City South Stop (island platform)	233	tonnes	36
	Commonwealth Park Stop (island platform)	302	tonnes	47
	Pavements	5,754	tonnes	892
	Kerbing	2,262	tonnes	351
	Drainage sumps	599	tonnes	93
	Street lighting foundation	142	tonnes	22

Activity	Sub-activity	Qty	Units	GHG emissions (t CO_2-e)
	Parkes Way bridge	925	tonnes	143
	Trackforms and sleepers	4,100	tonnes	636
	Bridge deck	283	tonnes	44
	Utilities	1,165	tonnes	181
Precast concrete	Edinburgh Ave Stop (side platforms)	37.25	m^3	1592
	City South Stop (island platform)	19.165	m^3	1990
	Commonwealth Park Stop (island platform)	22.15	m^3	1592

Appendix B

Operation GHG emissions inventory calculation

1.0 Overview

The following appendix provides a summary of the equations used to estimate annual greenhouse gas (GHG) emissions from Project operation and includes assumptions regarding data inputs based on the design provided at the Works Approval (WA)/Development Application (DA) lodgement. GHG emission sources from operation include:

- Power consumption from the electrical grid
- Maintenance activities including:
  - Fuel combustion from:
    - Routine maintenance associated regular street sweeping of light rail
    - Mobile equipment used for major preventative maintenance activities
    - Shipping and road transport for port transfers associated with replacement of Light Rail Vehicles (LRV)s.
  - Embodied energy of materials replaced as major preventative maintenance including:
    - Steel from LVRs and lithium-ion batteries
    - Asphalt
    - Pavements (stone, brick, and concrete pavers) from footpaths
    - Concrete.

Emissions from operation and routine maintenance of the project have been calculated and reported on both an annual basis and an assumed asset service life of 50 years. GHG emissions from major preventative maintenance activities have been calculated for an asset service life of 50 years. The product service life of key materials used to estimate the total GHG emissions from embodied energy from maintenance activities are discussed below.

2.0 Scope 1 emissions

2.1 Fuel combustion

2.1.1 Methodology

Scope 1 emissions for diesel combustion associated with street sweeping for maintenance of the light rail were estimated using the following equation listed in Section 2.2 of the *National Greenhouse Accounts Factors* (2021)

$$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1000}$$

Where:

E_{ij}	=	Emissions of gas type (j) (CO_2, CH_4 or NO_x form fuel type in tonnes of CO_2^{e-}
Q_i	=	Qi is the quantity of fuel type (i) (kilolitres or gigajoules) combusted for transport energy purposes
EC_i	=	ECi is the energy content factor of fuel type (i) (gigajoules per kilolitre or per cubic metre) used for transport energy purposes — see Table 4. If Qi is specified in gigajoules, then ECi is 1
EF_{ijoxec}	=	EFijoxec is the emission factor for each gas type (j) (which includes the effect of an oxidation factor) for fuel type (i) (kilograms CO_2^{-e} per gigajoule) used for transport energy purposes.

Scope 1 GHG emissions from fuel combustion were estimated using emission factors for general transport using diesel oil listed under Table 4 of the *National Greenhouse Accounts Factors* (2021). An emission factor of 70.2 CO_2^{-e}/Gigajoule (GJ) was used based on the combined emission factors for diesel oil for CO_2, CH_4 and N_2O. An energy content factor for diesel oil of 38.6 GJ/kL was adopted in accordance with Table 4 of the *National Greenhouse Accounts Factors* (2021).

Estimated fuel quantities are provided in **Section 2.1.2.** A detailed emissions inventory for Scope 1 emissions is also provided in **Section 2.1.2.4**.

2.1.2 Quantity estimations

The following subsections provide a detailed description of fuel quantity estimations from key sources of fuel combustion during regular and major preventative maintenance operations. Product service life estimations for major preventative maintenance operations have been derived from the following sources:

- *Civil Infrastructure Design Standards, Version 1.0, TLR CI 12500 ST* (TfNSW 2017)
- *Roads and Maritime Supplement to Austroads Guide to Pavement Technology, Part 2 Pavement Structural Design, Version 3.0, RMS 11.050,* (RMS 2018).
- *Durability Requirements for Civil Infrastructure, Version 1.0, TLR CI 12002 ST (TfNSW 2017a)*
- *Engineering Specification, SPC 232 Concrete Sleepers, Version 1.2 (TfNSW 2019)*

2.1.2.1 Street Sweeping

Street sweeping for maintenance of the light rails was assumed to occur once per month and cover 3.316 track kilometres per sweeping event. This would equate to 39.8 vehicle kilometres travelled (VKT) per month.

Fuel consumption was based on medium truck size in Table 5-4 of the TAGG 2013 guidance document with a fuel consumption rate of 0.00028kL; equating to 0.011kL per year. This equates to 0.557kL over an asset life of 50 years.

2.1.2.2 Asphalt replacement

Heavy duty asphalt is assumed to have a design life (product service life) of 40 years (RMS 2018). It is assumed that all asphalt would be replaced once over the asset life once. A total of 18,282 m^2 of asphalt was assumed to be replaced based on plant take of information for the bill of quantities (BOQ).

To calculate the amount of diesel fuel consumed from utilisation of mobile equipment during replacement a value of 0.0045kL/m^2 was assumed based on the TAGG 2013 fuel consumption value for maintenance of deep strength asphalt. This equates to 82.3 kL of fuel required for major preventative maintenance of asphalt over the asset life.

2.1.2.3 Pavement replacement

Pavements used for footpaths were assumed to have a product life of 20 years, half the design life of heavy-duty pavements (RMS 2018). It was assumed that all pavements would be replaced twice over the asset life. Pavement areas for stone, concrete and brick pavements were based on plant take of information for the BOQ.

To calculate the amount of diesel fuel used by mobile equipment for pavement replacement activities a value of 0.0107kL/m^2 was assumed based on the TAGG 2013 value for maintenance of concrete pavement. Diesel fuel quantities for major preventative maintenance for pavement are provided in Table 1. The total diesel fuel consumption was assumed to be 425.5 kL over an asset life of 50 years.

Table 1 Diesel fuel quantities required for maintenance of pavements

Replacement activity	Area (m^2)	Product service life	No. replacements	Diesel fuel consumption (kL)
Stone pavement	19,367	20	2	414.5
Concrete pavement	112	20	2	2.4
Brick pavement	405	20	2	8.7
			Total (kL)	**425.5**

2.1.2.4 Concrete replacement

Fuel combustion from major preventative maintenance work associated with concrete have been limited to key structures with a design life of 50 years or less. This includes concrete kerb and pavement, track sleepers, the bridge deck of the Parks Way Bridge and pavement to platforms and ramps at the Edinburgh Stop, City South Stop and Commonwealth Park Stop. All kerb and pavements were assumed to have a product life of 40 years (RMS 2018), track sleepers were assumed to have a product life of 50 years (TfNSW 2019) and bridge decking was assumed to have a product service life of 20 years (wearing surface) (TfNSW 2017). Maintenance of track slabs has also been included which has a product life of 100 years, here an assumed five percent are assumed to be replaced over the asset life. Concrete quantities were derived from the plant take of information for the BOQ.

To calculate the amount of diesel fuel used by mobile equipment for concrete replacement works a value of 0.02 kL/m for kerb construction and a value of 0.0107kL/m^2 for concrete pavement maintenance was assumed from TAGG 2013. Diesel fuel quantities for major preventative maintenance for concrete works is provided in Table 2. The total diesel fuel consumption was assumed to be 427.2 Kl over an asset life of 50 years.

Table 2 Diesel fuel quantities required for maintenance of concrete structures

Replacement activity	Material Qty	Product service life	No. replacements	Diesel fuel consumption (kL)
Kerbs	10747.0 m	40	1	82.3
Pavements	14569.3 m^2	40	1	414.5
Track sleepers	2566.9 m^2	50	1	2.4
Track slabs	11486.2 m^2	100	0.05	8.7
Bridge deck	536.6 m^2	20	2	214.9
Edinburgh Ave Station (pavers)	565.0 m^2	40	1	155.9
City South Station (pavers)	225.0 m^2	40	1	27.5

Replacement activity	Material Qty	Product service life	No. replacements	Diesel fuel consumption (kL)
Commonwealth Park Station (pavers)	261.0 m^2	40	1	6.1
			Total (kL)	**427.2**

2.1.3 Detailed emissions inventory

An emission inventory breakdown for combustion of diesel fuel from street sweeping maintenance activities both annually and over the asset life of 50 years is provided in **Table 3**.

Table 3 Detailed emissions inventory for Scope 1 diesel fuel consumption for regular maitenance

Activity	Distance per trip (m)	Annual trips	VKT	Fuel Qty (kL/year)	Emission factor (kg CO_2^{e-}/GJ)	GHG emissions (t CO_2^{-e}) Per annum	GHG emissions (t CO_2^{-e}) Asset Life
Street Sweeping (Maintenance)	3.316	12	39.8	0.011	70.2	0.030	1.51

Table 4 Detailed emissions inventory for Scope 1 diesel fuel consumption for major preventative maintenance

Activity	Sub-activity	Fuel Qty	Emission factor (kg CO_2^{e-}/GJ)	GHG emissions (t CO_2^{-e}) Asset Life
Asphalt replacement	Pavement	82.3	70.2	222.9
Pavement replacement	Stone pavement	414.5	70.2	1123.0
	Brick pavement	2.4	70.2	6.5
	Concrete pavement	8.7	70.2	23.5
Concrete replacement	Kerbs	214.9	70.2	582.4
	Pavements	155.9	70.2	422.4
	Track sleepers	27.5	70.2	74.4
	Track slabs	6.1	70.2	16.7
	Bridge deck	11.5	70.2	31.1
	Edinburgh Ave Station (pavers)	6.0	70.2	16.4
	City South Station (pavers)	2.4	70.2	6.5
	Commonwealth Park Station (pavers)	2.8	70.2	7.6

3.0 Scope 2 emissions

3.1 Methodology

Scope 2 emissions for fuels used for transport energy purpose were estimated using the following equation listed in Section 2.3 of the *National Greenhouse Accounts Factors* (2021)

$$Y = Q \times \frac{EF}{1000}$$

Where:

Y	=	Scope 2 emissions measured in CO_2^{-e} tonnes
Q	=	Quantity of electricity purchased (kilowatt hours)
EF	=	Emission factor, for the State, Territory, or electricity grid in which the consumption occurs (kg CO_2^{-e} per kilowatt hour)

Table 5 the NGAF 2021 lists Scope 2 emission factor for electricity usage in NSW and ACT as 0.79 kg CO_2^{-e}/kWh. In both 2020 and 2021 ACT achieved its goal to source 100% of its electricity from renewable generators in accordance with its Sustainable Energy Policy. The NGA emission factor for the Project of 0.79 kg CO_2^{-e}/kWh is considered overly conservative for ACT given NSW's high dependence on fossil fuels. The ACT Greenhouse Gas Inventory For 2020-21 (ACT, 2021) reported ACT as having sourced 100% renewable energy, and therefore a zero emission factor was adopted. This is considered appropriate for future years also due to the ACT's ongoing commitment to renewing offset emissions through the use of Large Generation Certificates (LGC's).

Given the ACT achieved its goal to source 100% of its electricity from renewable generators in 2020 this value is considered more representative emission factor to estimate potential construction impacts from the Project.

As such an emission factor of 0 kg CO_2^{-e}/MWh for the 2020-2021 financial year has been reported for operational impacts; noting electrical consumption is still shown for transparency.

3.2 Quantity estimations

3.2.1 Bore pump

It was assumed that a single 3kW motor bore pump would be required during operation and would operate for 7hrs every third day, totalling 2,555 kWh per annum. This equates to 126 MWh over an asset life of 50 years.

3.2.2 Signalling

Electricity usage for signalling has been based on eight signalised intersections/crossings across the alignment with a total of 114 sets of signals required: with two units per set each requiring lights. Each light was assumed to be an LED bulb with a power of 15W; equating to 10.26kW. Each signal was assumed to be operating continuously for a total electrical consumption of 89,878kWh per annum. This equates to 4,494 MWh over an asset life of 50 years.

3.2.3 Lighting

Assumed electricity usage from lighting at light rail stops and for street lighting are provided in **Table 5**. The following assumptions were used to derive estimated values:

Lighting at stations has been derived from drawing plans used in the preliminary energy model for the Project. Statutory lighting is expected to operate at 100% capacity from dusk to midnight and 20% capacity from midnight to sunrise. All accent lighting is assumed to operate at 100% capacity from dusk to midnight only.

An estimated 320 lights would be required for street and pedestrian lighting. Each streetlight was assumed to be and LED light of 207W (66.24kW total) operating 12 hours per day.

Table 5 Estimated electrical usage from station and street lighting per annum

Location	kWh per annum	MWh over asset life (50 years)
Edinburgh Ave Avenue	11,871	128
City South	7,893	4,494
Commonwealth Place	9,354	1,456
Street	290,131	14,507

3.2.4 LRV Battery Charging

Energy usage from charging LRV batteries has been estimated from the *Canberra Light Rail Stage 2, Traction Power Model* (ARUP 2021). The traction power model provides an estimate of the energy consumption from the onboard energy storage system (OESS) both north and southbound between Alinga Street and Hopetown Circuit covering a distance of 7.133 km. From these values as presented in **Table 6**, OESS energy use was calculated at 10.0kWh per southbound trip and 9.3 kWh per northbound trip.

Services from the existing light rail timetable updated on 1 November 2021 north and southbound between Alinga Street and Gungahlin Place were used to estimate the number of trips annually as shown in **Table 6**. It is assumed that with the introduction of five additional LRV existing services along the extended line would maintain the same level of service. Based on the number of trips annually the total OESS energy use were calculated (731,145 kWh). A charging efficiency of 90% consistent with the traction power model was then used to estimate the annual electrical consumption of 812,383 kWh. Over an assumed asset life of 50 years this equates to a total energy consumption rate of 61,203 MWh.

Table 6 Estimated electrical usage from LRV battery charging

Parameter	Value	Unit
Wire free distance (Alinga Street to Hopetoun Circuit)	7.133	km
Stage 2A track distance	1.658	km
Total OESS capacity	136.08	kWh
OESS operational capacity	93.1	kWh
Southbound OESS energy use (Alinga to Hopetoun)	43.1	kWh
Southbound OESS energy use (Stage 2A)	10.0	kWh
Annual southbound trips	37,752	Trips/y
Annual southbound energy use	378,207	kWh
Northbound OESS energy use (Hopetoun to Alinga)	40	kWh
Northbound OESS energy use (Stage 2A)	9.3	kWh
Annual northbound trips	37,960.0	Trips/y
Annual northbound energy use	352,938	kWh
Total OESS energy use annually	731,145	kWh
Charging efficiency	90	%
Total annual OESS electrical consumption	812,383	kWh
Total OES electrical consumption over asset life (50 years)	61,203	MWh

3.3 Detailed emissions inventory

A breakdown of Scope 2 emissions is provided in **Table 7**. As discussed in **Section 3.1** due to the use of renewable energy in ACT the emission factor for Scope 2 emissions is assumed to be negligible thus GHG emissions from electricity usage during operation are also expected to be negligible.

Electrical consumption has still been reported however for transparency. Additionally, if the more conservative emission factor from NGAF 2021 for NSW and ACT for Scope 2 emissions of 0.79 kg CO_2-e/kWh; which accounts for electricity generated by fossil fuels was assumed this would equate to 967 t CO_2-e emissions annually of 49,351 t CO_2-e emissions over 50 years.

Table 7 Detailed emissions inventory for Scope 2 GHG emissions from operation per annum

Activity	Sub-Activity	Electricity usage (kWh per annum)	GHG emissions (t CO_2-e per annum)	GHG emissions (t CO_2-e asset life)
Bore Pump		2,555	0 (2.0)	0 (100.9)
Signalling		89,878	0 (71)	0 (3550.2)
Lighting	Edinburgh Ave Avenue	11,871	0 (9.4)	0 (468.9)
	City South	7,893	0 (6.2)	0 (311.8)
	Commonwealth Place	9,354	0 (7.4)	0 (369.5)
	Street	290,131	0 (229)	0 (11,460.2)
LRV Battery Charging		812,383	0 (642)	0 (32,089.1)
	Total	**1,224,065**	**0 (967.0)**	**0 (48,350.6)**
GHG emissions denoted in brackets are GHG emissions using the more conservative emission factor from NGAF 2021 for NSW and ACT for Scope 2 emissions of 0.79 kg CO_2-e/kWh				

4.0 Scope 3 emissions

4.1 Fuel combustion

4.1.1 Methodology

Scope 3 emissions for fuels used for international transport of replacement LRV's from Spain have also been included for major preventative maintenance. It is assumed that the five LRV's required for Stage 1 have a product life of 30 years and would require one replacement over the asset life. LRV's from Stage 1 retrofitted as part of Stage 2 A works have been excluded from the GHG emission estimates.

Both Scope 3 emissions from international shipping and domestic port transfer have been included. The emission factor for shipping of 0.00893 kg CO_2^{-e}/tkm (tonnes. Kilometres) has been adopted from CERT and is based on emissions from a transoceanic freight ship. Similarly, from CERT 2018 an emission factor of 0.0726 kg CO_2^{-e}/tkm has been adopted for road transport and is based on an articulated truck with an 28t capacity. Transport activity values in tkm for import of LRVs are provided in **Section 4.1.2.**

A detailed emissions inventory for Scope 1 construction emissions is also provided in 4.1.3.

4.1.2 Quantity Estimations

Greenhouse gas emission estimates for international imports are based on the mass of material (in tonnes) and the distance travelled (in kilometres). The mass of steel from the LRV's was estimated at 208t and is discussed in more detail in Appendix A of the GHG Technical Report. Estimated travel distances included both shipping and road transport as modes of travel.

The LRV's are to be imported from Spain; and an estimated one-way travel distance of 15,965 km[1] for freight shipping was estimated for a transoceanic freight ship between the Port of Valencia, Spain and Port Kembla, Australia. Based on the estimated steel mass and shipping distance a quantity of 3,322,642 tkm was used to estimate shipping emissions from LRVs.

Emissions from road transport was also included for port transfers between Port Kembla and the project site for LRV deliveries. A one-way distance for domestic port transfers was estimated at 252 km. The total VKT travelled was calculated based on one-way distances for an articulated truck with a 28t capacity operating; with a carrying capacity of 80% applied; equating to 22.4t per trip. Rounded up to the nearest whole value approximately 10 trips would be required for LRV deliveries. Using the estimated load per trip of 22.4t and total VKT of 2,520 an activity value of 56,448 tkm was estimated for domestic port transfers.

Assumed values used to estimate the total tkm for international shipping and road transport for international import of LVRs are provided in **Table 8**.

Table 8 Estimated activity values for international import of replacement LRVs

Activity	Haul Route (one way) (km)	Steel Qty (t)	VKT (km)	Transport Activity (tkm)
Shipping	15,965	208.1	-	3,322,643
Road Transport	252	208.1	2,520	56,448

4.1.3 Detailed Emission Inventory

A detailed emissions inventory breakdown for fuel consumption from international import of replacement LRVs is provided in **Table 9**.

Table 9 Detailed emissions inventory for Scope 3 fuel consumption for replacement of LRVs

Activity	Sub-activity	Qty	Unit	GHG emissions (CO_2^{-e})
	Shipping	3,322,643	tkm	29.7

[1] Estimated shipping distances were calculated using https://sea-distaces.org and assumed that LVRs would travel from the Port of Valencia. Spain to Port Kembla, Australia and for Rail Steel from Venice, Italy to Port Kembla, both via the SueZ Canal.

Activity	Sub-activity	Qty	Unit	GHG emissions (CO_2^{-e})
International Imports	Road transport	56,448	tkm	4.1
Total GHG emissions (t CO_2^{-e})				**191.2**

4.2 Embodied energy

4.2.1 Methodology

Scope 3 emissions from embodied energy of key materials required for key major preventive works has been estimated over a 50-year asset life. Scope 3 emissions from the embodied energy of construction materials was estimated using the following equation

$$Y = Q \times EF$$

Where:

Y	=	Scope 3 emissions measured in CO_2^{-e} tonnes
Q_i	=	Quantity of construction material per unit of measure (tonnes of cubic metres) or capacity of the battery in kilowatt hours
EF	=	Emission factor of construction material in tCO_2^{-e}/kWh

Emission factors for embodied energy of construction materials and reference sources are supplied in Table 10. Assumed product life and number of replacements are also provided in the table below and are discussed further in Section 4.1 above also.

Table 10 Emission factors for embodied energy in replacement materials for major preventive maintenance

Material	Assumed classification	Product service life	No. replacements	Emission factor	Reference
LRV	Structural steel beams (imported)	30	1	3,000 $kgCO_2^{e-}$/t	CERT 2017
LRV Batteries	Average emission factor for LFP batteries	7	7	135.7 $kgCO_2^{e-}$/kWh	Haao *et. al* 2017
Asphalt	Hot mix asphalt with 0% RAP	40	1	65$kgCO_2^{e-}$/t	CERT 2017
Pavement	Stone pavement (granite)	20	1	93$kgCO_2^{e-}$/t	Hammond & Jones 2008
	Brick pavement	20	1	0.38tCO_2^{e-}/t	TAGG 2013
	Precast concrete 40 MPa pavement	20	1	398$kgCO_2^{e-}$/t	CERT 2017
Concrete	Poured concrete (40MPa)	Variable see Section 4.2.2.4		0.155tCO_2^{e-}/t	TAGG 2013
	Precast concrete (40MPa)	40	1	398 kg CO_2^{e-}/m^3	CERT 2017
Note: LEP stands for lithium ferro phosphate					

4.2.2 Quantity Estimations

4.2.2.1 Light rail vehicle and battery replacement

Major preventative maintenance associated with light rail vehicles over the assumed 50-year asset life for embodied energy emissions was assumed to include:

- Replacement the five new LRVs imported for Stage 2A. The LRVs were assumed to have a product life of 30 years and would require one replacement over the asset life.
- Replacement of lithium ferrophoshate in the five new LRVs and 14 existing LRV vehicles every seven years equating to seven replacements over the asset life.

Steel weight of each LRV is assumed to be equal to the tare load of each vehicle prior to being fitted with batteries. The tare load of each vehicle was assumed to be 41.625t which equates to a total of 208t, based on the replacement of five LRVs once during the asset life.

Each of the five new LRVs and 14 existing LRV vehicles will be fitted with two modules, each containing three batteries. The batteries are lithium ferrophoshate and collectively hold 136.08kWh in total for each LRV; with a combine total of 2,585.52kWh.

Each of the five new LRVs and 14 existing LRV vehicles will be fitted with two modules (68.04kWh per module), each containing three batteries. The LFP batteries collectively hold 136.08kWh in total for each LRV (total OESS capacity); with a combine total of 2,585.52 kWh. Maintenance of the Project would require replacement of the lithium ferrophosphate batteries for each of the 19 LRVs seven times over the asset life equating to a total of 18,098.6 kWh.

4.2.2.2 Asphalt replacement

Heavy duty asphalt is assumed to have a design life (product service life) of 40 years (RMS 2018). It is assumed that all asphalt would be replaced once over the asset life once. Asphalt replacement quantities have been obtained from plant take off information for the BOQ for the Project and assumed asphalt density of 2.4 t/m^3 (CERT 2017) are summarised in **Table 11.** A total of 4,899 tonnes of asphalt is assumed to be replaced over the 50-year asset life.

Table 11 Assumed asphalt replacement quantities

Replacement activity	Qty (t)
Replace pavements and roads (PT1)	341
Replace pavements and roads (PT2)	2,358
Replace pavements and roads (PT3) partial reconstruction	932
Replace pavements and roads (PT4) asphalt mill and resheet	1,068
Replace pavements and roads (PT6a) Conc driveway/bikepath with asphalt	11
Replace pavements and roads (PT10) Asphalt carpark & bikepath	39
Replace pavements and roads (PT11a) Replace concrete pavement with asphalt surface	150
Total	4,899

4.2.2.3 Pavement replacement

Pavements used for footpaths were assumed to have a product life of 20 years, half the design life of heavy-duty pavements (RMS 2018). It was assumed that all pavements would be replaced twice over the asset life. Pavement areas for stone, concrete and brick pavements were based on plant take of information for the BOQ. Assumed pavement material quantities for replacement are provided in Table 12 and a more detailed breakdown of material quantities for stone pavers is provided in Appendix A of the GHG Technical Report.

Table 12 Assumed pavement replacement quantities for major preventative maintenance.

Pavement Type	Qty per replacement	No. replacements over Asset Life	Qty over asset life
Stone	865.7 t	2	1731.3 t
Brick	6.3 t	2	12.6 t
Cement	32.4 m^3	2	64.8 m^3

4.2.2.4 Concrete replacement

Emissions from embodied energy from major preventative maintenance concrete work associated with concrete have been limited to key structures with a design life of 50 years or less. This includes:

- Concrete kerb and pavements as well as precast concrete pavers to each platform and pedestrian ramps all assumed to have a product life of 40 years (RMS 2018).
- Concrete track sleepers assumed to have a product life of 50 years (TfNSW 2019)
- Concrete slab used for the Parks Way Bridge deck assumed to have a product life of 20 years, consistent with wearing bridge deck surfaces (TfNSW 2017)

Maintenance of track slabs has also been included which has a product life of 100 years (TfNSW 2017), here an assumed five percent are assumed to be replaced over the asset life.

Concrete quantities were derived from the plant take of information for the BOQ and replacement quantities over the asset life are provided in Table 13.

Table 13 Assumed concrete replacement quantities for major preventative maintenance

Replacement activity	Sub activity	Qty per replacement	No. replacements over Asset Life	Qty over asset life
Kerbs	Poured Concrete	2,262.2 t	1	2262.2 t
Pavements		5,753.7 t	1	5753.7 t
Track sleepers		495.9 t	1	495.9 t
Track slabs		3,444.8 t	0.05	172.2 t
Bridge deck		257.6 t	2	515.2 t
Edinburgh Ave Station (pavers)	Precast concrete	28.3 m^3	1	28.3 m^3
City South Station (pavers)		11.3 m^3	1	11.3 m^3
Commonwealth Park Station (pavers)		13.1m^3	1	13.1 m^3

4.2.3 Detailed Emissions Inventory

A detailed emissions inventory breakdown for embodied energy from materials used for major preventive maintenance activities over the asset life is provided in **Table 14**. Note the per annum value assumes a seven-year lifespan.

Table 14 Detailed emissions inventory for Scope 3 embodied energy of materials for major preventative maintenance

Activity	Sub Activity	Qty	Emission factor	GHG emissions (t CO_2^{-e} over asset life)
LRV Replacements	LRVs (steel)	208.1 t	135.7 $kgCO_2^{e-}$/kWh	2456.0
	LFP battery	18098.6 kWh	3000 $kgCO_2^{e-}$/t	624.4

Activity	Sub Activity	Qty	Emission factor	GHG emissions (t CO_2^{-e} over asset life)
Asphalt Replacement	Pavement	4899.0 t	65 $kgCO_2^{e-}$/t	318.4
Pavement Replacement	Stone pavement	1731.3 t	93 $kgCO_2^{e-}$/t	161.0
	Brick pavement	12.6 t	0.38 tCO_2^{e-}/t	4.8
	Concrete pavement	64.8 m^3	398 $kgCO_2^{e-}/m^3$	25.8
Concrete Replacement	Kerbs	2262.2 t	0.155 tCO_2^{e-}/t	350.6
	Pavements	5753.7 t	0.155 tCO_2^{e-}/t	891.8
	Track sleepers	495.9 t	0.155 tCO_2^{e-}/t	76.9
	Track slabs	172.2 t	0.155 tCO_2^{e-}/t	26.7
	Bridge deck	515.2 t	0.155 tCO_2^{e-}/t	79.8
	Edinburgh Ave Station (pavers)	28.3 m^3	398 $kgCO_2^{e-}/m^3$	11.2
	City South Station (pavers)	11.3 m^3	398 $kgCO_2^{e-}/m^3$	4.5
	Commonwealth Park Station (pavers)	13.1 m^3	398 $kgCO_2^{e-}/m^3$	5.2
Total GHG emissions (t CO_2^{-e})				**5,037.2**