NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

FINAL REPORT

P117: Developing a Pavement Sustainability Assessment Tool for Queensland – Year 1 (2019/20)

ARRB Project No.: 015265

Author/s: Brook Hall, Robert Kochhan, Steven Middleton, Umer Chaudhry, Lydia Thomas

Prepared for: Queensland Department of Transport and Main Roads

Final

14 July 2020

AN INITIATIVE BY: arrb Queensland Government

SUMMARY

In the next 30 years, the transport system aims to harness emerging technologies and services to improve the use of current roads and transport systems. Increasingly, decision making incorporates climate change mitigation (i.e. emissions reductions), recycling and waste management and sustainable procurement considerations.

New pavement technologies provide an opportunity to increase the use of recycled or non-standard materials in road construction and maintenance. TMR has invested in research and development of innovative pavements through the NACOE program. The P106 project found that these new pavement designs typically have a lower embodied carbon content (i.e. release less greenhouse gases over the pavement's lifecycle), compared to standard pavement designs that use virgin materials. Some new technologies also require less construction materials due to reduced layer thicknesses and lower lifecycle cost savings.

The pavement Sustainability Assessment Tool will enable TMR to lead and implement comparative assessment of project-specific pavement designs to inform decision-making around pavement design.

The tool will allow a concurrent evaluation of the economic and environmental sustainability impacts of alternative project-specific pavement designs. These evaluation results will help inform decisions regarding material selection, design and long-term maintenance strategy over the pavement lifecycle.

The tool will enable users to:

- Evaluate and compare the economic and environmental sustainability impacts of project-specific pavement design alternatives
- Evaluate use-phase environmental sustainability impacts of modified road designs (horizontal and vertical curvature options)
- Quantify sustainability outcomes aligned with government sustainability targets and value for money indicators
- Make smarter procurement decisions regarding material selection, design and long-term maintenance strategy considering pavement lifecycle performance, sustainability and cost
- Provide data suitable for annual reporting or sustainability reporting.

Ultimately, the implementation of the pavement sustainability assessment tool will assist with driving the adoption of innovative pavement technologies and designs that contribute to Queensland's waste reduction, landfill diversion and recycled material use targets, and delivering on its vision to become a sustainable, low-waste, circular economy.

This report describes the scope of the Sustainability Assessment Tool to be developed. The model scoping exercise completed in 2019-2020 involved a user-requirements review, scoping the model outputs, determining the necessary input data requirements, building relevant reference datasheets, assessing TMR's capability to produce essential customisable input data, and outlining the key model outputs.

During the delivery of the model scoping requirements phase, TMR has partnered with Western Australia Main Roads' to deliver the next phases of the project. As part of this joining of projects, the delivery of a minimum viable product has been accelerated and is being delivered in tandem with the Milestone 1 report.

ARRB's view is that the proposed model scope meets a number of TMR's operational and policy needs, and TMR has ready access to the essential data needed to run the proposed model. This finding supports the development a proof of concept Excel-based model to enable consistent and reliable lifecycle sustainability and economic assessments of innovative pavement designs. This proof of concept model will be based on a minimum viable product (MVP) approach – one that meets TMR's basic needs and allows for further testing and enhancements thereafter.

At the time of finalising this document, the MVP model had been well developed and was undergoing user testing.

1 CONTENTS

2 TABLES

3 FIGURES

1 INTRODUCTION

This paper describes the scope of the Sustainability Assessment Tool to be developed for Queensland's Department of Transport and Main Roads (TMR).

The 'user requirements review and model scoping' provides TMR with a clear project scope that aligns with its policy and practical needs and is achievable given the data required to run the model. Specifically, it documents:

- the review of user-requirements, including policy and stakeholder needs and alignment with the Infrastructure Sustainability Council of Australasia's (ISCA's) Infrastructure Sustainability (IS) ratings requirements
- the proposed model scope and key outputs
- input data requirements and an outline of reference datasheets
- the assessment of TMR's internal capabilities to produce essential customisable input data.
- This is the first deliverable of the project.

The project is concurrently developing a Minimal Viable Product (MVP) Excel-based model to enable consistent and reliable lifecycle sustainability and economic assessments of innovative pavement designs, based on the in-principle agreed model scope.

The next steps will involve:

- Developing enhancements to the model to extend and improve its capabilities
- Developing and testing a user-friendly interface and guidance material
- Investigating the feasibility of extending the model to non-pavement road infrastructure applications.

1.1 WARRIP-NACOE PARTNERSHIP

In late November 2019, Main Roads Western Australian (Main Roads) and ARRB commenced a sustainability assessment tool project under the WARRIP research program. In February 2020, ARRB and TMR started an equivalent project under the NACOE research program. During February and March 2020, the WARRIP and NACOE project teams discussed project similarities, including alignment of final deliverables. On 12 March 2020, the WARRIP and NACOE project teams agreed to collaborate on the development of the tool as a joint project. A joint project plan was signed by the ARRB, Main Roads and TMR Project Leaders and the WARRIP and NACOE Agreement Managers on 29 April 2020.

The purpose of the collaboration is to realise:

1. A consistent end-product and comparable model outcomes. The end-product will support a single source of truth, giving consistency and reliability for road agencies and industry Australia-wide and minimise ongoing maintenance costs.
2. Achieve efficiencies in project delivery, which can be reinvested into additional project enhancements. Prioritised model enhancement options will be described in the joint WARRIP-NACOE step 2 report.

A Project Working Group (PWG) was established to oversee the strategic direction of the joint project and to discuss project progress and any issues that arise. The PWG consists of the ARRB, Main Roads and TMR Project Leaders as well as senior technical and governance advisors from each of the project partner organisations.

1.2 PROBLEM STATEMENT

New pavement designs, technologies and process provide opportunities to use or increase the use of recycled and innovative materials in road construction and maintenance. These new pavement designs typically have a lower embodied carbon content (i.e. release less greenhouse gases over the pavement's lifecycle), compared to standard pavement designs that use virgin materials. Some new technologies also require less construction materials (reduced layer thicknesses), offer improved pavement performance and lifecycle cost savings.

However, existing standards, specifications and processes do not necessarily allow for, or adequately encourage the use of innovative, low-carbon pavement design technologies. Existing lifecycle assessment tools, such as the Infrastructure Council Sustainability Assessment (ISCA)'s Infrastructure Sustainability (IS) Materials Calculator (a supporting tool for the IS ratings process) can be used for standard pavement technologies; however, it does not have the flexibility to quantify innovative pavement designs, such as those using recycled materials – due to existing tool limitations.

TMR pavement engineers, sustainability professionals and other decision makers do not currently have adequate tools to concurrently evaluate the economic and environmental sustainability impacts of innovative road pavement technologies. These evaluation outcomes will help TMR to inform better decisions regarding material selection, design and long-term maintenance strategy over the pavement lifecycle.

This model scoping study outlines a detailed approach to address this capability gap by developing a user-friendly sustainability assessment tool to enable consistent and reliable quantification and comparison of lifecycle sustainability and economic impacts of pavements.

This project will address these capability and process gaps over a two-year program.

1.3 PROJECT PURPOSE

The overall purpose of the project is to enable TMR and its road research and project partners to quantify and compare lifecycle sustainability and economic impacts of innovative pavements consistently and reliably. This will contribute to:

- improved capability in assessing sustainability impacts of innovative pavement designs and technology
- better understanding of the impacts of innovative pavement designs, leading to better long-term investment decision making
- emissions reductions
- cost savings
- improved pavement performance
- reduced landfill and support circular economy goals
- promotion of innovative pavement and recycling industries (incl. job creation).

1.4 PROJECT OBJECTIVES

The overall project objective is to develop a user-friendly sustainability assessment tool to assess the lifecycle economic and environmental (emissions and waste) impacts of innovative pavements, compared with traditional road technologies and designs. Specifically, the tool will allow TMR to:

- Compare lifecycle economic and environmental sustainability opportunities of innovative road pavement technologies against traditional road technologies
- Quantify and compare sustainability (i.e. GHG emissions, waste, reuse and recycling) outcomes aligned with government sustainability targets and value for money indicators (e.g. emissions/$NPV).
- Make smarter procurement decisions regarding material selection, design and long-term maintenance strategy considering pavement lifecycle performance, sustainability and cost.

The proposed pavement sustainability assessment tool will facilitate the assessment of economic and environmental opportunities of innovative pavements on a lane-kilometre, or project/route basis. The assessments would be applicable to any new pavement works in Queensland with a focus on pavement designs or projects that incorporate innovative pavement materials/technologies. Technology-based assessment outputs will use a common lane-kilometre basis to show the difference between the base and alternative cases and enable trend comparisons over time and comparison versus policy targets.

Project-based assessments are expected to help inform options analysis, detailed pavement designs and material selection by contractors.

The assessment results will help inform decisions regarding material selection, design and long-term maintenance strategy over the pavement lifecycle. It will also provide data suitable for annual reporting or sustainability reporting.

The objective of deliverable 1 (this paper) is to describe the scope of the model to be developed.

1.5 PROJECT SCOPE

The sustainability assessment tool will assess lifecycle greenhouse gas emissions and costs of a base case pavement design versus comparable alternative(s).

1.5.1 INCLUSIONS

The project scope includes:

- Scoping and developing a user-friendly lifecycle assessment model for the assessment of environmental and economic impacts of pavements and surfacings.
- Capability to model innovative pavement technologies and materials (subject to data availability), i.e. not constrained to business as usual, or standard pavement designs and materials
- Lifecycle assessment phases: extraction and production, construction, maintenance, materials transport and end of life disposal.
- Alignment and compatibility with existing lifecycle assessment tools, such as the ISCA 2.0 materials calculator and the Carbon Gauge tool.

1.5.2 EXCLUSIONS

The model development excludes non-pavement infrastructure elements, such as bridges, culverts, drainage, earthworks, vegetation clearing, delineation, lighting, signals and signage. However, the latter steps in the project will conduct a feasibility assessment of the inclusion of these elements in possible future developments of the model.

Safety impacts will not be considered as part of this assessment tool – and should be conducted separately.

1.6 BACKGROUND

1.6.1 QUEENSLAND STATE ROAD NETWORK

TMR manages one of the largest road networks in Australia, with responsibility for approximately 33,000 kilometres of the state-controlled road network. Queensland’s state road network has an estimated value of almost $47 billion. Road pavements contribute to a significant cost component and present a major opportunity to achieve sustainability outcomes across the road network, including reduced greenhouse gas emissions and waste.

1.6.2 CURRENT USE OF INNOVATIVE AND RECYCLED MATERIAL IN ROAD PAVEMENTS

TMR is committed to delivering sustainable, resilient infrastructure focused on transitioning to a circular economy, reducing waste and emissions and increasing recycling to provide all Queenslanders with a cost effective and reliable road network. TMR already allows the use of recycled materials in its pavement:

- **Glass –** TMR currently permits up to 5% recycled crushed glass as a substitute for sand and aggregate in asphalt pavements.
- **Crumbed rubber -** Used tyres are recycled and processed into crumbed rubber, which is blended into bitumen to be used in asphalt and sprayed seals. Crumbed rubber not only recycles old tyres, but it can improve the longevity and performance of roads. 1.1 million equivalent passenger tyres are forecast to be saved from landfill on TMR projects by June 2021.
- **Construction and demolition (C&D) waste -** C&D waste is material recovered from construction and demolition sites such as concrete, brick and glass, and can be used as an alternative to natural aggregates and sand in road bases. TMR currently allows restricted percentages of crushed concrete and brick in pavements under MRTS35. TMR is also investigating the use of C&D waste in concrete. Up to 8,000 tonnes of raw material could be saved if C&D waste is used to build 1km of road.
- **Reclaimed asphalt pavement (RAP) -** When asphalt is removed from existing roads it is processed into reclaimed asphalt pavement (RAP) material. This RAP can be incorporated back into new asphalt. The use of RAP provided cost savings, reduces our reliance on raw aggregate and bitumen and diverts waste from landfill. Up to 40% of new asphalt can be made from RAP however this is often limited by the volumes of suitable quality RAP recovered.
- **Insitu stabilisation -** Insitu stabilisation of existing roads is undertaken by blending stabilising agents (including fly ash and slag) to strengthen and rejuvenate aging pavements. This results in very little waste sent to landfill and reduced consumption of new materials. Up to 6,000 tonnes of waste diverted from landfill per kilometre of road that is stabilised.
- **Hot-in-**place Asphalt recycling (HIPAR) - HIPAR removes, rejuvenates and relays asphalt in a single pass. This results in very little waste sent to landfill without needing to consume new materials and with minimal impacts on traffic. 2 million m2 of pavement has been recycled using HIPAR.
- **Rubbelisation -** Rubbelisation is used to rehabilitate and recycle existing concrete pavements by fracturing the existing concrete pavement into small, interconnected pieces before a new road is constructed over the top. 1st trial of rubbelisation in Queensland has been undertaken by TMR.
- **Fly ash and blast furnace slag -** Fly ash and blast furnace slag are industrial wastes from coal fired power plants and steel production and can be used to replace up to 70% of the cement used in pavements or up to 35 percent of the cement used in concrete. Use of fly ash can help reduce GHG emissions by up to 70%.

TMR is continually researching innovative technologies and using recycled materials to construct sustainable resilient infrastructure which benefits the environment, community, and economy. Current opportunities include:

- **Glass –** TMR is finding further ways to use recycled crushed glass as a substitute for sand and aggregate in road materials. TMR is investigating the use of recycled glass in concrete, as bedding and backfill sand around pipes and up to 20 per cent in gravel road bases and up to10% recycled glass in asphalt and gravel road bases.

- **Plastics in infrastructure -** TMR is investing in research to understand the opportunities for incorporating recycled plastics into road infrastructure. A major focus is ensuring long-term performance benefits for Queensland's roads as well as the safety and sustainability of the environment and the community now and in the future.

- **Recycled materials in earthworks drainage and concrete -** TMR is exploring new opportunities for the use of recycled materials in earthworks, drainage and concrete, focusing on diverting waste from landfill and supporting a circular economy. Recycled materials such as glass, bottom ash and C&D waste have the potential to be used in these applications (NACOE 2020).

1.6.3 SUSTAINABILTY ASSESSMENT

The Infrastructure Sustainability Council of Australia (ISCA) defines sustainable infrastructure as 'infrastructure that is planned, designed, constructed and operated to optimise environmental, social and economic outcomes over the long term' (ISCA 2020b). The ISCA definition is consistent with other sustainability rating tools and with global sustainability definitions including the UN Sustainable Development Goals (UN SDGs) i.e. 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

TMR conducts infrastructure sustainability assessments for high valued road investments (>$100m) using the ISCA infrastructure sustainability (IS) rating process.

The IS rating scheme is an industry compiled sustainability performance assessment tool that evaluates sustainability in planning, design, construction and operations in all infrastructure. The rating process requires the quantification of greenhouse gas (GHG) reductions and sustainability benefits.

The IS rating scheme 1.0 was first released in 2012. Version 2.0 was released on 1 July 2018. Key modifications of the version 2.0 include alignment to UN Sustainable Development Goals on Projects.

ISCA urges that all future infrastructure sustainability assessments be conducted in accordance with ISCA v 2.0.

ISCA 2.0 includes the following components:

- The IS Technical Manual
- IS Rating Tool Score Card (IS score card)
- IS Material Calculator
- Various guidelines that support the application of the tool.

1.6.4 EARLIER WORK

In August 2019, ARRB delivered an innovative pavement lifecycle assessment research project to the Queensland Department of Transport and Main Roads (TMR) under the National Assets Centre of Excellence (NACOE) research program. The 'Assessing the Potential Greenhouse Gas Emissions Reductions and Sustainability Benefits of Innovative Pavements' project (NACOE P106) quantified the lifecycle greenhouse gas (GHG) and waste reduction and economic benefits from the use of innovative pavement technologies and compared to traditional pavement technologies and designs. It also identified a range of sustainability benefits (such as reduced material quantities used and disposed of, climate resilience performance, and road alignment outcomes) from the use of these technologies over the pavement lifecycle.

To enable the research outcomes, ARRB developed an Excel based tool that based on comparable Australian and international models and emissions factors. However, the ARRB-developed, NACOE P106 model is unique. Compared with existing tools used in Australia, the NACOE P106 model:

- allows flexibility of various pavement designs, not limited by drop down menus. This allows for the evaluation of new and innovative pavement designs.
- allows for the assessment of the resilience of pavements to extreme weather events and lifecycle savings.
- allows for the evaluation of vehicle emissions from pavement design and alignment decisions and including considering various emission reduction technologies.
- evaluates the GHG emissions, material waste/recycling outputs cost over the pavement lifecycle.

- aids smarter procurement decision making.

This project builds on the development of the NACOE P106 model, with further planned enhancements including greater flexibility in the assessment design, more reportable metrics, and an improved user-interface and user guidance.

1.6.5 PROJECT STEPS

The project consists of the following key steps:

- Step 1: User requirement review, review of existing lifecycle assessment tools and model scoping
- Step 2: Model enhancements – developing and testing a MVP assessment model, investigating enhanced user-interface delivery options, and considering hosting and licensing arrangements
- Step 2B: Investigating the feasibility and implementing feasible model enhancements
- Step 3: User-interface development – delivering user-friendly interface and developing a user-guide.
- Step 4: Model expansion opportunities – Investigating opportunities to extend model and its application for broader road infrastructure construction/maintenance use (culverts, barriers, etc.).

Section 1.6.6 outlines the method applied for the step 1 - user requirements review and model scoping. Appendix A outlines the proposed method for steps 2 to 4 of the project (subject to revision).

This paper documents the research, development and findings of step 1 – the user requirements review and model scoping.

1.6.6 USER REQUIREMENT REVIEW AND MODEL SCOPING

The user requirements review and model scoping exercise involved:

- conducting a user-requirements review
- scoping the minimum viable product model
- assessing whether existing products could meet the user needs
- determining the necessary input data requirements, building relevant reference datasheets, and assessing TMR's capability to produce essential customisable input data
- outlining the key model outputs.

2 STEP 1: USER REQUIREMENTS

The user requirements review aims to document TMR's pavement sustainability assessment needs. These needs can then be mapped against a list of model capabilities to inform a minimum viable product model scope. This user requirements review and model capability mapping ensures that ARRB can deliver a product that meets TMR's needs. Documenting TMR's needs also provides clarity and transparency to the direction of the model scope and its development.

The user requirements review adopted the following methodology:

1. Identify what TMR needs
2. Identify how the tool will satisfy TMR's needs
3. Map relationships between the 'needs' and the 'hows'.

2.1 IDENTIFYING NEEDS AND HOW THE TOOL WITH SATISFY THE NEEDS

This section describes how TMR's needs were identified. The outcome of the assessment is presented upfront in section 2.1.1 with the detailed analysis following.

2.1.1 SUMMARY

Table 2.1 presents a summary of TMR's policy, stakeholder and IS rating needs as determined by assessment of the project objectives, discussions with the TMR NACOE Program Leader and key TMR's stakeholders, and through desktop research.

Table 2.1: User requirements review: policy, stakeholder and IS ratings needs

Needs
Policy needs
Reduce whole of life GHG emissions, by enabling new infrastructure solutions
Reduce the impact of waste on the environment by avoiding waste, improving resource recovery and increasing the use of recycled materials
Transition to a circular economy for waste to benefit human health, the environment and the economy, by improving the management of material flows
Build economic opportunity by building demand for recycled products and improving information to support innovation, guide investment and enable informed consumer decisions.
Stakeholder needs
A user-friendly analysis tool
A flexible analysis tool
Consistent and reliable results
Data suitable for annual and sustainability reporting
Smarter procurement decisions
High performing and sustainable infrastructure
IS rating needs
Alignment with IS rating processes
Adoption of IS v 2.0
Lifecycle assessments

Needs
Compares base case versus alternative case(s)

Source: ARRB

2.1.2 NEEDS ASSESSMENT APPROACH

To identify TMR's needs, a review was conducted of:

- the sustainability policy environment in Queensland: policy objectives, GHG emissions and waste reduction targets
- Stakeholder needs analysis, including consultation with prospective users of the model
- IS 2.0 rating scheme requirements – lifecycle assessment scope and reporting.

2.1.3 SUSTAINABILITY POLICY ENVIRONMENT

Summary of identified policy needs

- Reduce GHG emissions, by enabling new infrastructure solutions (amongst many other initiatives)
- Reduce the impact of waste on the environment by avoiding waste, improving resource recovery and increasing the use of recycled materials
- Transition to a circular economy for waste to benefit human health, the environment and the economy, by improving the management material flows
- Build economic opportunity by building demand for recycled products and improving information to support innovation, guiding investment and enabling informed consumer decisions.

Queensland's greenhouse gas reduction targets and climate transition strategy

The Queensland Government is committed achieving net zero greenhouse gas emissions by 2050 and has set an interim target of reducing greenhouse gas emissions by 30 per cent (from 2005 levels) by 2030. The *Queensland Climate Transition Strategy* outlines how Queensland proposes to prepare for the transition and meet a target of zero net emissions by 2050 (Queensland Government 2017).

This policy intent is also captured in the *Queensland Transport Strategy* which states that the transport network will be integrated, accessible, environmentally sustainable and more convenient, and that all Queenslanders will benefit from improved safety, efficiency and affordability. A key strategic direction to achieve this goal is transitioning to a net zero emissions transport system (Department of Transport and Main Roads 2020).

Queensland will support the transport system's transition to net zero greenhouse gas emissions by improving efficiency and enabling new vehicle technologies and infrastructure solutions. Identified initiatives to do this include adopting a whole-of-life approach to transport emissions, by minimising emissions across the planning, design, delivery, operation and maintenance of infrastructure and services.' (Department of Transport and Main Roads 2020).

The *Queensland Transport Strategy's Action Plan* will be developed and released in 2020 to support the strategy.

Waste reduction and recycling policies and targets

Queensland has a vision to become a zero-waste society, where waste is avoided by reuse and recycling to the greatest extent possible.

The *Queensland Waste Management and Resource Recovery Strategy* 2019 (Queensland Government, 2019) outlines the following relevant strategic policies:

- Reducing the impact of waste on the environment
- Transitioning to a circular economy for waste
- Building economic opportunity.

Strategic investment in diverse and innovative resource recovery technologies and markets will produce high-value products and generate economic benefits for the state. These strategic plans are supported by initiatives including the landfill levies, plastic bag bans, resource reduction industry plans, etc.

Applicable waste reduction and recycling targets include:

- 25% reduction in household waste by 2050
- 90% of waste is recovered and does not go to landfill by 2050
- 75% recycling rates across all waste types by 2050.

Table 2.2 outlines Queensland's landfill waste diversion.

Table 2.2 Queensland's landfill waste diversion targets (recovery rate as a percentage of total waste generated)

Stream	Baseline (2018)	2025	2030	2040	2050
Municipal	32.4%	55%	70%	90%	95%
Commercial and Industrial	47.3%	65%	80%	90%	95%
Construction and Demolition	50.9%	75%	85%	85%	85%
Overall	45.5%	65%	80%	85%	90%

Source: Queensland Government (2019)

Table 2.3 provides Queensland targets for waste that is reported as recycled or reused, specifically excluding material from which energy is recovered.

Table 2.3 Recycling rates (as a percentage of total waste generated)

Stream	Baseline (2018)	2025	2030	2040	2050
Municipal	31.1%	50%	60%	65%	70%
Commercial and Industrial	46.5%	55%	60%	65%	>65%
Construction and Demolition	50.9%	75%	80%	>80%	>80%
Overall	44.9%	60%	65%	70%	75%

Source: Queensland Government (2019)

Landfill Levy

From 1 July 2019, a levy zone will also be applicable for most of Queensland's disposal of commercial waste (Queensland Government 2019c). The levy is intended to reduce the amount of waste generated, grow the resource recovery and recycling industry and create new jobs. For construction and demolition (C&D) waste, the applicable levy is $75 / tonne (Queensland Government 2019b). The waste levy for all classifications is proposed to increase by $5/tonne on 1 July each year (Queensland Government 2019b). The levy is applicable for most of the East Coast of Queensland.

National waste policy and action plan

National policies influences the state-based policies and responses. The 2018 *National Waste Policy* provides a framework for collective action by businesses, governments, communities and individuals until 2030 (Australian Government Department of Environment and Energy, 2018). The policy identifies five overarching principles underpinning waste management in a circular economy:

- Avoid waste
- Improve resource recovery
- Increased use of recycled materials and build demand for recycled products
- Better manage material flows to benefit human health, the environment and the economy
- Improve information to support innovation, guide investment and enable informed consumer decisions.

The *National Waste Policy Action Plan* creates targets and actions to guide investment and national efforts to 2030 and beyond. These include:

- Ban the export of waste plastic, paper, glass and tyres, commencing in the second half of 2020
- Reduce total waste generated in Australia by 10% per person by 2030
- 80% average recovery rate from all waste streams by 2030
- Significantly increase the use of recycled content by governments and industry
- Phase out problematic and unnecessary plastics by 2025
- Halve the amount of organic waste sent to landfill by 2030
- Make comprehensive, economy-wide and timely data publicly available to support better consumer, investment and policy decisions.

Waste export ban

In November 2019, the Council of Australian Governments agreed that waste (such as) plastic, paper, glass and tyres that have not been processed into value-added material should be subject to an export ban. The ban commences on 1 July 2020 with a phased approach:

- All waste glass by July 2020
- Mixed waste plastics by July 2021
- All whole tyres included bladed tyres by December 2021
- Remaining waste products, including mixed paper and carboard by no later than 30 June 2022 (Council of Australian Governments 2020)

Queensland State Infrastructure Plan

The Queensland State Infrastructure Plan stipulates that Queensland Government infrastructure projects greater than $100m shall undertake sustainability assessments and recommend sustainability assessments for projects $50m-$100m.

2.1.4 STAKEHOLDER NEEDS ANALYSIS

The following stakeholders have been identified for this project:

- TMR
- Road planners
- Road (pavement) designers
- construction industry
- Queensland community.

Identified stakeholder needs and potential benefits

On 26 March 2020, the TMR and ARRB Project Leaders led two workshops with the potential end users of the sustainability assessment tool. The first workshop included members from the infrastructure planning group within TMR and the second included members from the detailed design group.

The planning group undertakes high level assessments of a project's feasibility (not usually at the level of specifying pavement designs and materials). If they were to use the model it would be for options analysis with assessments focussed on use phase GHG emissions outcomes. The core focus of the tool is on comparing pavement design attributes, it also has capability to vary other pavement parameters such as traffic loads and distributions, and alignment options.

The Road/Pavement designers' group is responsible for specifying a project's detailed design elements, including pavement material selection, and is likely to be the key user of the model and explore its full capabilities. i.e. comparing the different outcomes of specifying a standard road pavement design versus an innovative design. The sustainability assessment tool is purpose built to meet this need.

TMR stakeholders also identified a possible third user group, i.e. construction contract managers who would be focused on cost effective delivery of quantifiable benefits (e.g. tonnes of GHG emissions reductions, and potential cost savings due to less waste and haulage). The sustainability assessment tool may be useful in informing reasonable and feasible contractual requirements to meet these goals.

Responses to feedback from the planning and detailed design groups is outlined in Appendix A.

In addition to the two groups above, the sustainability and environment group would likely benefit from the sustainability outputs. Investment and procurement groups would also benefit from the economic outputs.

Table 2.4 outlines the identified user requirements of the proposed tool and the expected benefits for each stakeholder.

Table 2.4: Stakeholder needs analysis

Stakeholder	Stakeholder needs	Benefits
TMR	A user-friendly tool – tool can not take days to use. The user must be able to enter information in a short period of time Support both options analysis and detailed pavement design considerations Flexibility to change the pavement parameters (design) and lifecycle assessment period – based on the lifecycle scope e.g. years of assessment and dimensions of road Compatible/transferable data input requirements to existing systems. Low/no costs for users Publicly available tool Capability to evaluate innovative and new sustainable pavement designs and road alignment compared to traditional road technologies Consistent and reliable results Alignment with: • Sustainability and waste policy, processes and targets. • business case assessment or other assessment methods. Supports procurement processes (e.g. helping to define contractual requirements) and decision making	Flexibility to evaluate different designs not limited by existing tools. GHG emissions and cost savings, including: • Materials cost savings • Construction cost savings • Other agency cost savings • Reduced GHG emissions Ability to vary a broad range of pavement attributes, including traffic levels and distribution, road alignment etc. which will impact the use phase GHG emissions. Inform decision making outcomes. Compatible with business case or other procurement and tender processes – planning, design and/or construction phase. Inclusion of additional sustainability criteria in procurement decision making. Diversion of waste away from landfill
Road (pavement) design and construction industry	Understanding of the additional reporting and evaluation required for tending processes. Consistent communication of product sustainability benefits for tending purposes e.g. CO2-e emissions on lane.km basis Easy, cheap access to the tool	Potential access to the tool to communicate information to TMR on a consistent basis. Assist Queensland achieve the IS rating requirements where there are currently limitations with the existing tool.
Queensland community, including road users	High performing and sustainable infrastructure.	Confidence in government decision making that incorporates lifecycle sustainability impacts Potential to model road user costs or other corridor decisions on the public and/or environment.

Source: ARRB analysis

2.1.5 IS 2.0 RATING SCHEME REQUIREMENTS

The IS ratings scheme awards sustainability and innovation credits (up to 110 points) for sustainable infrastructure projects (see Appendix E for background on the ISCA and the IS rating scheme). IS version

2.0 is the current edition of the rating scheme, which was released on 1 July 2018, however many projects remain using ISv1.2. ISCA is encouraging its members to transition to the new IS 2.0 for all future IS ratings.

The proposed assessment tool will be compatible with the assessment requirements of the IS version 2.0 (Planning, Design & As-Built) for the following sustainability credits:

- energy efficiency (Ene-1)
- resource recovery (Rso-4)
- material lifecycle impact measure and management (Rso-6).

Each of these credits (Ene-1, Rso-4 and Rso-6) require a lifecycle assessment to obtain ratings points. ISCA defines infrastructure lifecycle consistent to the sustainability assessment tool's lifecycle phases (as outlined in section 3.2), however where ISCA uses the term 'operations', the sustainability assessment tool defines the lifecycle phase as 'use/operations' reflecting the broader use phase, including road user emissions as impacted by the pavement and design and construction, maintenance and alignment options.

In line with these credits, the model will quantify:

- lifecycle CO_2-e emissions (Ene-1 and Rso-6), modelled for scope 1, 2 and 3 emissions.
- lifecycle materials used (tonnes), recycled and landfilled (Rso-4).

Conducting a lifecycle assessment will also contribute to the achievement of the economic viability and financial affordability (Ecn-4) credit which requires a whole of life costing that considers the total costs and potential benefits of the investment decision across its life.

Identified IS ratings needs

- Adoption of IS v 2.0
- Lifecycle assessments for energy efficiency, resource recovery and material lifecycle impact measure and management credits
- Compares a base case versus alternative case(s) – where each assessment case needs to be well defined and demonstrates a 'matching scope'.

The ISCA require lifecycle assessments to include a clear project boundary (i.e. extent of the assets and lifecycle stages) and the following lifecycle stages:

- Extraction and production
- Construction
- Operations
- Maintenance
- End of Life.

2.2 IDENTIFYING THE CORE MODEL CAPABILITIES

With reference to the identified needs, core model capabilities have been identified that will meet these needs. The core model capabilities have been categorised as operational and outputs capabilities.

2.2.1 OPERATIONAL CAPABILITIES

Operational capabilities include:

- **A user-friendly interface with user guidance material.** This involves developing a tool that is easy to follow and has relevant guidance (e.g. a user manual). Specific user-friendly design elements will be scoped after the completion of this model scoping exercise and delivered following the development of the MVP model (pending agreements to proceed beyond decision and hold points). To make the operation of the model as user friendly as possible, the model will be prefilled with background default/reference data. The model will also accommodate TMR's data names and definitions to allow existing datasets to be used, e.g. pavement designs, project briefs, tender and procurement information (see section 4.3 for input data categories).

- **Flexible assessment parameters** (e.g. technology-based or project/route-specific assessment, number of years of assessment, sensitivity and scenario modelling) to allow users to tailor assessments to meet a variety of specific needs.
  - **A)** Pavement design (technology) assessment results generated on a lane-kilometre basis with consistent default single lane-width and road length.
  - **B)** Project/route specific assessment results generated based on user-input of lane-width, number of lanes, road length, curvature and rise/fall. Sensitivity and scenario modelling enable testing the impact of varying one or more input variables.
  - Both technology based and project/route-based assessments can be defined for urban or rural applications by identifying the suitable traffic numbers and distributions (i.e. AADT and heavy vehicle percentages).
- **Flexible input data fields** that allow users to set local or project specific data values (e.g. pavement designs, road alignment and dimensions, haulage distances), that are not constrained by predefined design standards. Flexibility to change the pavement parameters (design) provides a capability to evaluate innovative and new sustainable pavement designs and compared to traditional road technologies.
- **Lifecycle analyses** incorporating lifecycle phases: extraction and production, construction, operations/use, maintenance, end of life (and transport and haulage – as a separated lifecycle phase)
- **Comparative analyses** of pavement lifecycle GHG emissions, waste and costs for a base pavement design against an alternative pavement design(s) over a user-defined lifecycle period
- **Minimum viable product development approach** including testing (i.e. consistency and reliability testing) and refinement.
- **Background reference (or default) data** is tailored in accordance with a preferential data hierarchy (e.g. use Queensland specific data as priority, followed by Australian/Australasian, international and lastly assumed/benchmark data).

2.2.2 OUTPUT CAPABILITIES

Output capabilities include metrics aligned with relevant government policy objectives, targets and measures, e.g. Carbon and waste reduction targets, recycling targets and cost effectiveness objectives.

Output lifecycle metrics include:

- GHG emissions – CO_2-e tonnes savings versus base case
- Waste (resource efficiency) – tonnes savings versus base case
- Economic - $NPV savings versus base case and Benefit Cost Ratios
- Economic (cost efficiency) - tonnes savings versus base case/$NPV savings versus base case

Output procurement metrics include:

- $NPV
- cost-benefit ratios
- cost efficiency metrics (e.g. tonnes of GHG saved/$).

TMR have an identifiable need for GHG reporting to meet state-wide carbon emissions reductions targets (e.g. reducing emissions by 30 per cent by 2030 and to zero by 2050). The proposed tool will enable quantification of pavement GHG emission for reporting purposes, i.e.:

- Total lifecycle GHG emissions
- Lifecycle GHG emissions for each lifecycle phase
- Lifecycle GHG emissions by emissions scope.

Unit of measure: CO_2-e tonnes savings versus base case

TMR also needs to be able to quantify its waste reduction and recycling efforts in accordance with the *Waste Management and Resource Recovery Strategy* 2019 (Queensland Government 2019a) (see section 2.1.3). The tool will enable quantification for reporting purposes, e.g.:

- Lifecycle material input quantities (for virgin and recycled materials used in construction and maintenance)
- End of life material output quantities (i.e. reused in the same pavement, sent away for recycling, or sent to landfill).

Unit of measure: tonnes savings versus base case.

Model lifecycle output capabilities to meet IS ratings needs include:

- CO_2-e emissions for scope 1, 2 and 3 emissions – for each lifecycle phase
- Quantity of materials used, recycled and disposed of as landfill (tonne).

The tool may also be used complement the ISCA rating process. Over the next project phases, the joint NACOE and WARRIP project teams will consider approaches to engage with ISCA to have the tool endorsed by ISCA and/or use its outputs to update the IS Materials Calculator.

2.2.3 PRIORITISED MODEL ENHANCEMENTS BEYOND THE MVP MODEL SCOPE

An MVP approach is used to identify and build a sustainability assessment model that meets TMR's basic needs (refer to section 2.1), and future enhancements can be considered once these basic needs are met. The following elements have been considered by the TMR Project Leader and ranked as priority enhancements to be considered for development after the delivery of the MVP model:

1. **Optimisation of pavement designs –** Applying an algorithm to the optimise the pavement design parameters to achieve minimal lifecycle GHG emissions and cost
2. **Other airborne pollutants -** Subject to data availability, the proposed model could also include other airborne pollutants such as those defined in the GRI 305: Emissions Standards (2016). In addition to the GHG emissions (covered in the current project scope), other airborne pollutants would include: Ozone-depleting substances (ODS), Nitrogen oxides (NOX), sulphur oxides (SOX), and other significant air emissions, such as, persistent organic pollutants or particulate matter. Enhanced model outputs would support the evidentiary requirements related to the IS Env-4 credit.
3. **Enviropoints -** Preliminary investigations into whether the model could incorporate Enviropoints (a broad measure of environmental impacts that go beyond GHGs[1]) have revealed that there is limited data available to calculate Enviropoints for non-standard, innovative pavement materials. Until a more mature dataset is available (most likely in the form of Environmental Product Disclosures for innovative pavements), calculation of Enviropoints will be limited to pavement types (i.e. designs and materials) already built into the IS Materials Calculator 2.0. ARRB will continue to investigate the feasibility of incorporating Enviropoints into the proposed model throughout its development and refinements.
4. **Water use -** Future development of the model could also consider the lifecycle water use of the infrastructure (IS credit Wat-1). This is out of scope for the current project.
5. **Energy usage –** At this stage of the development the proposed tool will not include kWh output for energy use (a component of IS credit Ene-1). Such outputs could be built into the model in future refinements.

An additional miscellaneous model enhancements package should also be considered to address issues and capability enhancements identified during the model development.

[1] Enviropoints are a weighted index consisting of points associated with the following environmental impacts: Global warming, ozone depletion, acidification, eutrophication, photochemical smog, abiotic depletion (elements and fossil fuels).

For each model enhancement a small targeted feasibility study will be required to determine whether the enhancement is possible, valuable to TMR and its stakeholders and the costs and timings necessary to deliver them. ARRB will provide advice to the Project Working Group (PWG) to facilitate a decision on which enhancements to pursue.

2.3 MAPPING RELATIONSHIPS BETWEEN THE 'NEEDS' AND THE 'HOWS'

Mapping the ‘needs’ to the ‘hows’ informs the next stage of the assessment including how the model will function and the core information inputs. Table 2.5 maps the identified policy, stakeholder and IS rating needs against the proposed model capabilities (i.e. the ‘hows’).

Table 2.5: User requirements review: needs vs how

Needs	Model capabilities
Policy	
Reduce GHG emissions, by enabling new infrastructure solutions	Supports GHG reporting to meet state-wide carbon emissions reductions targets
Reduce the impact of waste on the environment by avoiding waste, improving resource recovery and increasing the use of recycled materials	Outputs aligned with policy, goals and targets, e.g. sustainability, waste reduction and metrics and measures.
Transition to a circular economy for waste to benefit human health, the environment and the economy, by improving the management material flows	Outputs promote implementation of innovative materials and designs Outputs enable financial analysis/cost comparisons and multicriteria analysis
Build economic opportunity by building demand for recycled products and improving information to support innovation, guide investment and enable informed consumer decisions.	Outputs promote implementation of innovative materials and designs Outputs enable financial analysis/cost comparisons and multicriteria analysis
Stakeholder	
A user-friendly analysis tool	User friendly interface with user guidance material Input data aligned with existing data sources
A flexible analysis tool	Flexibility to change project parameters (options) and pavement design parameters (detailed design) Capability to evaluate innovative and new sustainable pavement designs and road alignment compared to traditional road technologies Pavement design (technology) or project/route-specific assessments
Consistent and reliable results	Background reference (or default) data is tailored in accordance with a preferential data hierarchy MVP development approach including testing (i.e. consistency and reliability testing) and refinement
Data suitable for annual and sustainability reporting	Outputs aligned with policy, goals and targets, e.g. sustainability, waste reduction and procurement metrics and measures. GHG reporting to meet state-wide carbon emissions reductions targets Quantifies recycled waste materials
Smarter procurement decisions High performing and sustainable infrastructure	Consistent basis for quantification allows for smart comparisons Outputs aligned with value for money indicators and enable financial analysis/cost comparisons Outputs quantify: • Materials cost savings • Construction cost savings • Other agency cost savings • Reduced GHG emissions

Needs	Model capabilities
	Promotes implementation of innovative materials and designs Outputs provide confidence in government decision making that incorporates lifecycle sustainability impacts
IS ratings	
Alignment with IS rating processes	Outputs compatible with ISCA 2.0 and carbon gauge assessments
Adoption of IS v 2.0	Outputs aligned with IS version 2.0 (Planning, Design & As-Built) for the following sustainability credits: • energy efficiency (Ene-1) • resource recovery (Rso-4) • material lifecycle impact measure and management (Rso-6).
Lifecycle assessments	Incorporates consistent lifecycle phases Quantifies scope 1, 2 and 3 emissions Quantifies materials used, recycled and disposed of as landfill (tonne)
Compares base case versus alternative case(s)	Compares base versus alternatives (with matching scopes)

Source: ARRB

3 MODEL SCOPE

In developing the model scope, a minimal viable product (MVP) approach has been adopted. An MVP approach is commonly used in IT and product developments. An MVP is a product with just enough features to effectively deploy the product and satisfy early customers, and to provide feedback for future product development.

Developers typically deploy the product to a subset of possible customers—such as early adopters (in this case to TMR's Project Manager, the NACOE Sustainability Stream Leader and potential internal users of the end product) who are more able to grasp a product vision from an early prototype, more likely to give feedback, and thought to be more forgiving. This strategy targets avoiding building products that customers do not want and seeks to maximize information about the customer per amount of money spent.

An MVP will deliver a product good enough to solve the core problem for customers and has only needed features to use it. This approach seeks to balance the minimum product – which meets all the non-negotiables , versus the most viable product that could be conceivably built. This balanced approached is presented in Figure 3.1.

Figure 3.1 Minimum viable product

Source: Gearheart 2020, https://gearheart.io/blog/how-build-minimum-viable-product-mvp/

Importantly, creating an MVP is not just building and releasing separate pieces of a future all-inclusive product. It is creating the simplest working form of the product that satisfies customer needs.

Section 2 outlined the model requirements from the user's perspective (inclusive of considerations of the policy environment and ensuring alignment with IS ratings processes) and identifying some key model scoping elements. This section builds on that analysis by assessing the completeness of the working model developed for the NACOE P106 project (see section 1.6.4 for an overview of the project) and opportunities to enhance it to build further value for TMR. A summary of the key model scope attributes is presented upfront in section 3.1 below.

3.1 SUMMARY OF KEY MODEL SCOPE ATTRIBUTES AND OUTPUTS

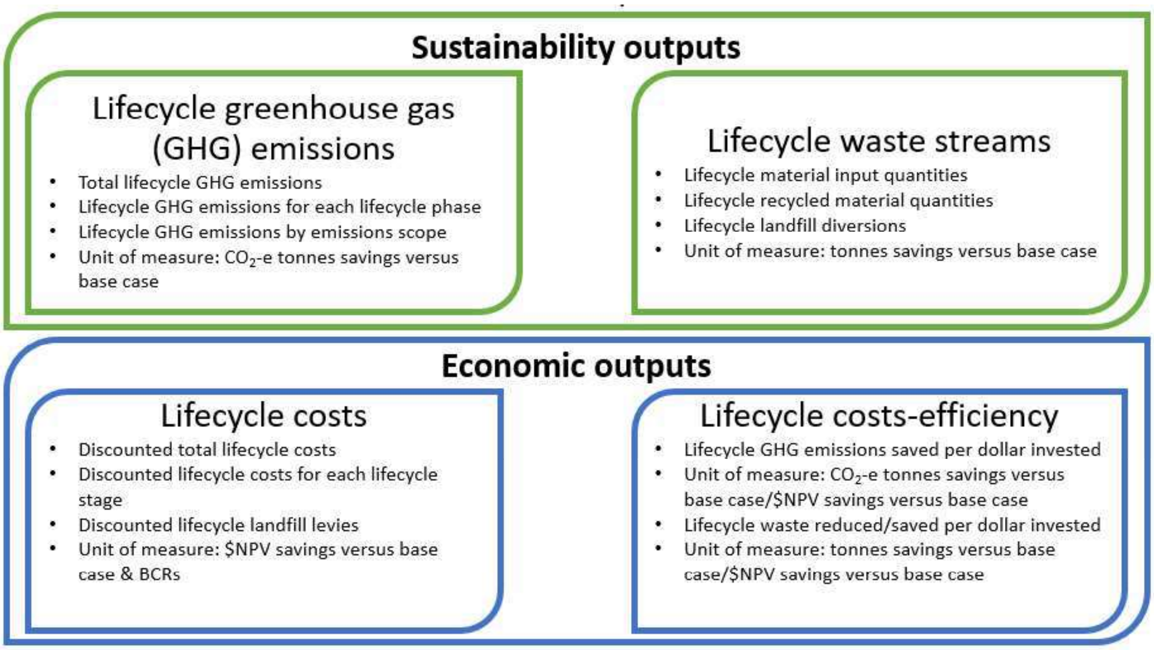
Key attributes of the model scope include:

- Compares pavement lifecycle GHG emissions, waste and costs for a base pavement design against an alternative pavement design

- Assessment over a user-defined lifecycle period[2]
- Pavement design (technology) or project/route-specific assessments.

The model will produce comparative sustainability and economic outputs, as presented in Figure 3.2.

Figure 3.2 Sustainability and economic outputs



Source: ARRB

3.1.1 GHG EMISSIONS AND GLOBAL WARMING POTENTIAL

GHG emissions refer to the release of GHGs into the atmosphere. The GRI Sustainability Reporting Standard on emissions (GRI 305: Emissions 2016) classified the following reportable airborne emissions as having greenhouse gases with a global warming potential (GWP): Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6), Nitrogen trifluoride (NF_3).

The global warming potential (GWP) is a calculation of how much individual GHGs contribute to global warming. The standard used to calculate carbon-dioxide equivalents is 100 years. For example, one tonne of methane in the air has the same effect as 12 tonnes of carbon dioxide over a 100-year time frame, or 1 tonne of CH_4 is equivalent to 12 CO_2-e.

The scope of the MVP is limited to carbon dioxide, methane and nitrous oxides which are the main contributors to global warming for transport infrastructure and operations. The global warming potential for identified GHGs is assumed based on the IPCC 5th assessment report as show in Table 3.1.

Table 3.1: Global warming potential of main greenhouse gases

Common name	Chemical formula	GWP values
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265

[2] A 40-year lifecycle period (standard pavement asset life) will be entered into the model as a default assessment period. Users can easily overwrite this default value (up to x years – where x will be defined during the model development phased based on software's capacity).

Source: Greenhouse gas protocol (2014)

3.2 SCOPING THE MODEL

Scoping the model involved assessing the foundational NACOE P106 model:

- for completeness, i.e. are all relevant lifecycle impacts included (e.g. consider including CO_2 impacts of materials processing and disposal).
- to scope enhanced capability to be used on a project assessment basis (as opposed to a technology assessment basis), e.g. ability to enter number and width of lanes, road length, location compared with source materials and disposal, etc. and ability to generate comparable results).

3.2.1 COMPLETENESS

To scope the completeness of the model, the pavement lifecycle is defined with its lifecycle phases and each phases' inclusions (inputs/outputs)

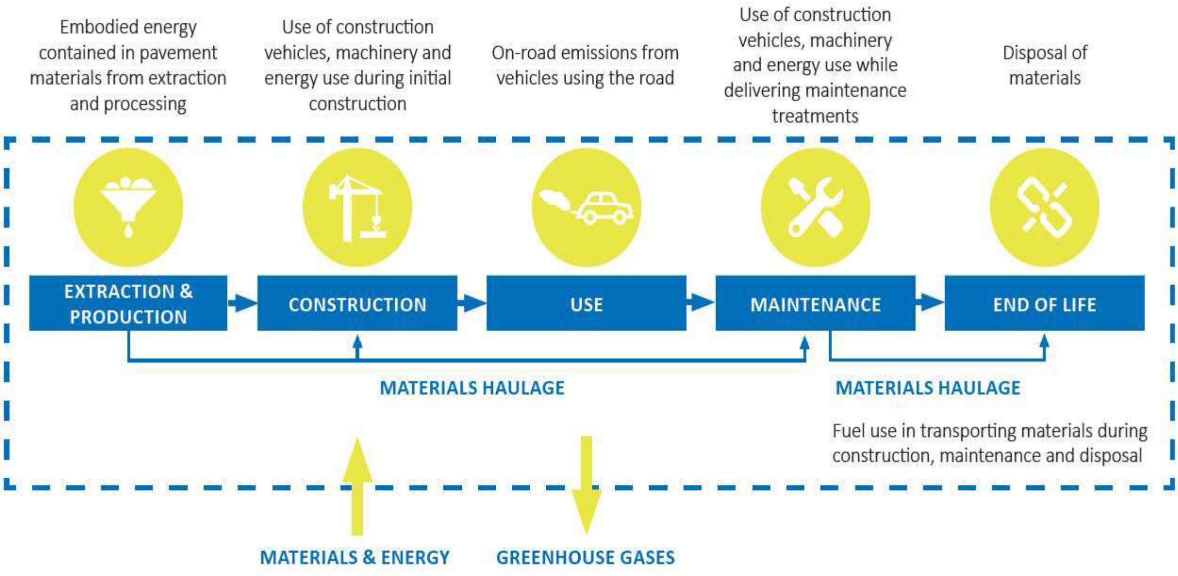
The pavements lifecycle consists of six phases:

- Extraction and production – Embodied energy contained in pavement materials from extraction and production, i.e. 'cradle to gate'
- Construction – Use of construction vehicles, machinery and energy use during initial construction
- Use/operations – On-road emissions from vehicles using the road
- Maintenance – Use of construction vehicles, machinery and energy use while delivering maintenance treatments
- End of life – Disposal[3], recycling or reuse of end of life materials
- Transportation/materials haulage – Use of heavy haulage vehicles in transporting materials to the project site for construction and maintenance, or from the project site to end of life disposal.

The pavement lifecycle follows a broadly linear process as indicated in Figure 3.3 below.

Figure 3.3 Pavement lifecycle phases

[3] While end of life disposal of pavements into landfill is rare (or perhaps even non-existent), it is important to include the phase in the lifecycle to demonstrate completeness and allow flexibility if needed (e.g. failed roads that can't be reused due to contamination, or inclusion of recycled content that hasn't yet been approved for reuse). Additionally, alignment with the IS ratings process requires the inclusion of end-of-life in the lifecycle assessments.



Source: ARRB

Transportation/materials haulage has three phases. These are:

1. from extraction (mine site) or production (asphalt plant) to construction (the project site)
2. from extraction (mine site) or production (asphalt plant) to maintenance (the project site)
3. from the project site to end of life (recycling facility, landfill or in-situ reuse)

Note: there may be several maintenance cycles over the pavement lifecycle assessment period.

Lifecycle inclusions

Lifecycle inputs include: Materials, energy and costs

- Materials and energy are inputs into the pavement lifecycle at the extraction and production, construction, maintenance and end of life phases. Energy is also inputted in the transportation/materials haulage phase.
- Cost inputs are applicable for all phases. However, use phase costs are attributable to both private and government road users (and not normally considered in the project cost estimates).

Lifecycle outputs include greenhouse gas emissions, material waste and lifecycle costs.

- Greenhouse gases[4] are generated in all lifecycle phases
- Waste can be generated in the maintenance and end of life phases of the pavement. If there is an existing road that is being replaced there may also be waste generated in the construction phase. Waste can also be avoided on-site by reusing or recycling materials in the construction and maintenance phases. At the end of life phase, materials can remain in the pavement, be recycled (off-site) or sent to landfill.

Emissions scopes

The tool will also be able to generate emissions outputs according to their emissions scope classifications, as defined in Table 3.2.

[4] Greenhouse gases included are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O).

Table 3.2: Emissions scope and model outputs

Emissions scope	Definition[5]	Inclusions
1	Direct emissions from owned or controlled sources	Construction – construction vehicle and machinery emissions Maintenance – maintenance vehicle and machinery emissions Transport – vehicle emissions
2	Indirect emissions from the generation of purchased energy	None. Excluded: Any off-site energy consumption generated for project planning and coordination (i.e. office-based energy use)
3	Indirect emissions (not included in scope 2) that occur in TMR's value chain including both upstream and downstream emissions	Materials extraction and production – embodied energy All use phase emissions (by vehicles travelling on the pavement) End-of-life emissions (where waste is chemically active after disposal – i.e. non-inert)

Source: World Resources Institute 2019 and ARRB

3.2.2 ENHANCED CAPABILITY

The model will include the following key features of enhanced capability (compared with the earlier model developed under the NACOE program):

- User-friendly interface – involves development of a tool that builds in background reference data to minimise user-burden, is easy to operate and has relevant guidance (e.g. a user manual). Detailed scope to be developed concurrently with the development of the MVP model (i.e. by July 2020)
- Flexibility – enabling TMR users to enter pavement and/or project specific data for tailored results.
- Technology or project/route assessments – enables comparable analysis on either a lane.km basis, or over a defined project boundary.
- Sensitivity and scenario analyses – to test the impact of specific input variables on the output results.

Proposed sensitivity and scenario analyses factors

Sensitivity analyses explore how model outputs are affected by changes in a single input variable. The analyses are useful where there is uncertainty in around particular input variables, or to understand the significance of the input variable to the outputs.

Scenario analyses involve defining a set of different input variable values (i.e. a scenario) and testing the outputs against a different scenario. Scenario analyses can be useful where there are multiple uncertainties in the input variables (e.g. future traffic projections, climate events and asset performance characteristics).

Table 3.3 outlines proposed sensitivities and scenario analyses factors that can be built into the model.

Table 3.3: Proposed sensitivity and scenario analysis factors

Sensitivity factors	Scenarios
Carbon price ($/$CO_2$-e tonne)	Resilience to climatic shocks, e.g. flood event
Discount rates (%)	Electric vehicle adoption rates
Haulage distances (km) – by transport phase and/or by material	Change in fuel standards
Waste disposal fees and levies ($/tonne)	
Road alignments (curvature: degrees/km and rise and fall: m/km)	

[5] World Resources Institute, Greenhouse gas protocol, FAQs, viewed 17 December 2019 at https://ghgprotocol.org/sites/default/files/standards_supporting/FAQ.pdf

Sensitivity factors	Scenarios
Speed and roughness	

Source: ARRB

4 INPUT DATA

The sustainability assessment model will require an array of specific customisable and non-customisable input data to generate useful results.

This section outlines the approach and outcomes of identifying the model's data requirements (based on the user requirements and minimum viable product model scope) and the views of likely users of the model in terms of appropriateness and accessibility of the necessary input data.

Noting the previous work with TMR on comparing the lifecycle GHG impacts of innovative pavement designs (i.e. the NACOE P106 project), the data assessment step (that was applied under the parallel WARRIP project) was determined to be unnecessary. The NACOE P106 project demonstrated that TMR had access to the relevant input data needed to run the model. Expert judgement is still required to determine the best and appropriate use of the available TMR data.

4.1 SUMMARY

The outcome of the work is a comprehensive database detailing all required input data for the pavement sustainability assessment tool, including data that needs to be produced by the user for specific assessment and reference dataset to pre-populate the model. The database aligns with the scope and structure of the sustainability assessment model as outlined in section 3.2. Key input data requirements include:

- Information about the model
- Assessment basis parameters
- Pavement designs
- Process parameters, i.e. pavement lifecycle construction and operation process parameters, including CO_2 emissions factors and costs
- Other parameter values, including material attributes and traffic levels and distributions
- Sensitivity analysis parameters.

Detailed descriptions and inclusions of these data categories are provided in Table 4.2 in section 4.3.3. The preliminary database entry fields and preliminary input reference data is provided in Appendix D. Note: these entry fields are subject to change during the development of the model itself.

Where possible the reference dataset uses QLD-specific data to reflect QLD-specific materials, practices, conditions and costs. This dataset will continue to be refined through more widespread research over the next project steps. The objective is to prioritise locally specific data in accordance with the data preference hierarchy presented in Table 4.1.

Table 4.1: Data preference hierarchy

Data hierarchy	Preference
QLD specific	Ideal – most preferred
Australasian	Next best
International	Acceptable
Assumed/estimated	Least preferable

Source: ARRB

ARRB insights include:

1. Most of the required input data is usually available within standard road pavement project documents. However, some data may need to be sourced from asset management systems (e.g. maintenance types and frequencies) or through new research (new material emissions factors).
2. The reference database and the assessment model will need to have flexibility to allow for the pavement layer and materials terminology commonly used by TMR (and Main Roads WA).

3. Clarification with TMR will be required to ensure that comparable reference values are used when data is sourced from different jurisdictions. This will help avoid misunderstandings or modelling errors.
4. There is a need to clarify which materials should be included in the assessment to maximise usability of the model for TMR projects.
5. The model will need to be able to accommodate inputs with different measures (e.g. volume only, volumes per pavement surface, mass etc.) to allow for greater flexibility, e.g. for assessing different pavement materials.

ARRB's view is that there is sufficient data availability and expertise within TMR that TMR users should be able populate the necessary 'essential' data requirements.

The gap analysis reveals opportunities to refine and improve some reference, or preferred data requirements through research, stakeholder consultation and modelling.

4.2 APPROACH

The approach used for identifying and assessing the input data availability was:

1. **Identify and categorise the model's input data requirements** to understand what data needs to be accessed, improved and built into the model as reference, or default data, and what data needs to be provided by TMR and its stakeholders (the users).
2. **Consult with the likely users of the model**. Sustainability assessments will require unique data inputs to be sourced by TMR. This sub-objective aims to test TMR's ability to source necessary unique data.
3. **Develop a reference database** that can be built into the sustainable pavement assessment model as the basis for assessing and comparing different innovative pavement technologies. The database will consist of generic input data that is tailored to the specific needs of TMR by including local Queensland-specific data wherever possible. The reference database minimises the data sourcing and inputting required by TMR users (assessors) and ensures reliable, consistent and tailored sustainability assessment outputs. The database will be built up using ARRB's existing datasets as well as new (updated and locally specific) data as identified through research. Part of this exercise will include a gap analysis to identify any data gaps or model shortcomings and devise solutions. Where there are data gaps, approaches are needed to address these. These approaches can include using alternative input data (e.g. assumptions or benchmark data) or amending the model to accommodate accessible data.

4.3 IDENTIFICATION AND CATEGORISATION OF THE PROPOSED MODEL'S DATA REQUIREMENTS

4.3.1 AIM

Identifying and categorising the proposed model's data requirements helps to understand what data needs to be identified, improved and built into the model as reference, or default data. Not all data can be pre-populated into the model and must be provided by TMR (the user of the model) for each assessment. Identifying and categorising essential assessment specific input data allows for an assessment against TMR's readily available data. This then informs refinements to the model to accommodate TMR's data.

4.3.2 METHOD

The identification and categorisation of the model's data involved:

- examining ARRB's existing pavement lifecycle assessment tool and undertaking a stocktake of every data input cell.
- identifying new data requirements needed to enhance the flexibility and capability of the model
- categorising and describing the input data that is needed to generate results.

4.3.3 FINDINGS/OUTCOMES

Examining ARRB's existing pavement lifecycle assessment tool

Examining ARRB's existing pavement lifecycle assessment tool (developed under NACOE P106) and undertaking a stocktake of every data input cell. This stocktake resulted in the identification of 377 lines of customisable and non-customisable data (including a mix of open text, drop-down menu selections, mandatory/optional data fields and reference data needs).

Identifying new input data requirements

Identifying new data requirements needed to enhance the flexibility and capability of the model (compared with the ARRB's existing tool). This included adding input data requirements around the assessment basis, i.e. assessment period (years), road alignment options, and construction and maintenance processes.

Categorising and describing the input data needed to generate results

The categorisation consolidated individual data entry cells into unique input data requirements (i.e. removing the duplication evident in comparing base vs alternative case data entry fields and repeated inputs that apply across multiple pavement layers or lifecycle phases). The categorisation and descriptions also help to filter and sort the data in different ways to enable different data analyses (e.g. data classes, sources, gaps, potential for improvement).

Table 4.2 identifies the key data input categorise and the types of data required.

Table 4.2: Key input data categories

Data category	Description
Information management	Information about the model: model version, date etc.
Assessment basis	Assessment parameters: assessment period (timeframe), ave lane width, ave number of lanes, road (segment) length, road alignment (average vertical grade and average horizontal curvature) and location (urban or rural).
Pavement design	Design data describing the pavement types (base case versus alternative(s)), their layers, materials and properties. Pavement name and specification of individual layers, e.g.: surfacing, intermediate, base, prime & seal, improved layer, select fill, subgrade For each layer, the following needs to be specified (if applicable): description, material, thickness, mass of material, density, and California Bearing Ratio (CBR). Pavement design data is needed for a reference case (base case) and for all alternative cases that are to be compared to the reference case.
Process parameters	Process data describes the construction, maintenance, use, transportation and end-of-life (removal) processes of the lifecycle of the pavement types. There are common process parameters applicable across all lifecycle phases, including - emissions and cost factors. As well as process parameters for specific lifecycle phases, including: • Construction – materials quantities and construction processes • Maintenance – roughness index (IRI or NAASRA) that determines maintenance intervals, thickness of every new layer and old / removed layer, maintenance processes • Transportation – vehicle types used, material haulage distances for every material and trip • Use – effects from vehicles using the road: annual average daily traffic (AADT) counts, percent of heavy vehicles (detailed traffic distribution is optional) and vehicle emissions data • End of life – fractions (%) of every pavement layer that are reused, recycled or sent to landfill, demolition costs, end-of-life material disposal costs, waste levies.
Other parameter values	Additional parameter values include: 1. Pavement material attributes, in particular material density and emissions (mine to end - of-production). Materials include asphalt, binder, cement, coarse or fine aggregate (e.g. crushed rock), concrete, crumb rubber, crushed glass, lime, recycled asphalt pavement, sand, soil, etc. 2. Input values for a separate fuel model which allow to determine the emissions from vehicles using the road: IRI/NAASRA, AADT and AADT growth, road category, average

Data category	Description
	speed (uninterrupted), traffic distribution and percentage of heavy vehicles, vehicle gross combination masses (GCM), vehicle fuel consumptions, ATAP VOC coefficients (K-factors), fuel emission factors (gCO_2-e/L) and global warming potentials of exhaust gas components.
Sensitivity analysis parameters	Parameters for the sensitivity analysis include: carbon prices, discount rate and emission reduction factors. Other parameters can also be analysed, e.g. fuel consumption, haulage distances, depending on assessment needs.

Source: ARRB

The key information sources for these data categories include:

- Road project or research design briefs, e.g. new road construction project, or pavement technology research study
- Pavement designs, e.g. pavement specifications, trials or laboratory test designs, Bill of Quantities from TMR's 3PCM system or otherwise
- Pavement engineering research, e.g. NACOE or WARRIP projects, Austroads reports, international research
- Industry data, e.g. pavement manufacturer designs (including any future Australian pavement environmental product declarations), construction contracts, tender submissions (subject to confidentiality)
- Lifecycle inventory data, e.g. AusLCI, Greenhouse gas assessment workbook, PaLATE
- Asset data or projections, e.g. road use and traffic distributions
- Source and site locations, or distances
- Parameter values, e.g. ATAP Guidelines.

Table 4.3 outlines the data classes used to categorise the input data. This categorisation allows for the identification of essential, preferred, optional and reference data.

Table 4.3: Data classes

Data classes	Description
Essential	TMR will need to produce this data for pavement analysis. Without essential data, analytical results are not possible/valuable. Essential data includes road/project design data
Preferred	Data that is either provided as default/ assumed input data or provided by TMR to generate more tailored (QLD or project-specific) results. ARRB will incorporate relevant default or assumed input data into the model, but allow TMR users to overwrite it, if better data is available. Preferred data includes construction and transport costs, Asset use parameters, transport distances.
Optional	Data that is not required to generate results, e.g. explanatory text, or for some types of analyses, e.g. sensitivity analyses
Reference	Input data that is built into the model and cannot be changed by TMR users. Reference data includes, fuel emissions intensity, vehicle operating cost coefficients.

Source: ARRB

Identifying reference / default data and customisable project-specific data

Reference/default data includes all reference data that will be built into the model.

Customisable data includes:

- Essential data - needed to operate the model
- Preferred data - ideal (but not essential) for refined results – reference data can be used in the absence of this data (e.g. haulage distances and costs)
- Optional data – required only for select assessments, e.g. scenario analyses/ sensitivity testing, or data that is not specifically required to generate results (e.g. explanatory text).

Ideally, most essential and preferred data should be QLD-specific (as shown in the data hierarchy in Table 4.1) in order to maximise the value of the model.

Identifying reference and customisable data requires determining:

- Crucial data needs to be provided by TMR to obtain best model outputs (essential data)
- Additional data can be provided by TMR to generate refined results (preferred data)
- Existing data can be used as default data (reference data)
- The remaining data gaps and ways to address these (e.g. through assumptions, national / international benchmark data, new research).

ARRB categorised the input data using the input data classes as outlined in Table 4.3 and filtered it to identify the reference data requirements, i.e. the 'reference' and 'preferred data'.

Table 4.4 show the filtered 'reference' input data that make up the base component of the reference database. This data cannot be overwritten by the user.

Table 4.4: Reference input data (cannot be overwritten by user)

Data category	Data type	Unit
Information management	Model version	Version no. revision no. (X.X)
	Latest version date	Date DD/MM/YYYY
Pavement design parameters (for each pavement layer and each assessment case)	Material density	Kg/m^3
	Embodied emissions (cradle to gate)	tCO_2-e
Construction process parameters (for each assessment case)	Construction emissions	tCO_2-e
Maintenance process parameters (for each assessment case and per maintenance cycle)	Maintenance emissions	tCO_2-e
	Roughness intervention levels (IRI/NAASRA values) for each year modelled	m/km
Transport process parameters (for each transport activity within the lifecycle and assessment case)	Transport vehicle emissions	tCO_2-e per 1 tonne moved 1km
Use phase process parameters (for each assessment year and assessment case)	Use phase emission	tCO_2-e
	Vehicle mass (GCM) by vehicle type	tonnes
	Vehicle fuel consumption by vehicle type	L/100km
	Fuel emissions conversion factors	Matrix of scaling factors
	Global warming potential factors	Scaling factors
	Vehicle operating cost coefficients	Matrix of scaling factors
End of life process parameters (for each pavement layer and assessment case)	End of life emissions	tCO_2-e

Source: ARRB

Table 4.5 shows the filtered 'preferred' input data categories that make up the remaining component of the reference database. This data can be overwritten by the user.

Note some data lines are provided in the reference data table can be overwritten by the model's users resulting in some duplication in data listed in Table 4.4 and Table 4.5.

Table 4.5: Preferred input data (can be overwritten by user)

Data category	Data type	Unit
Assessment basis	Assessment period	Years (default value=40)
	Number of assessment alternatives	No. (default value=1)
	Lane width	M (default value=3.5m)
	Lane length	Km (default value = 1km)
	Number of lanes	no. (default value = 1)
	Rise and fall	m/km (default value=0m/1km)

Data category	Data type	Unit
	Curvature	Degrees/km (default value=30°/km)
	Location	Urban/rural (default value=urban)
Pavement design parameters (for each pavement layer and each assessment case)	Material density	Kg/m³ (ARRB to reference data for each material)
	Embodied emissions (cradle to gate)	tCO_2-e (ARRB to reference data for each material)
Construction process parameters (for each assessment case)	Construction emissions	tCO_2-e (ARRB to reference data for each material)
	Construction costs	$/km
Maintenance process parameters (for each assessment case and per maintenance cycle)	Maintenance emissions	tCO_2-e (ARRB to reference data for each material)
	Maintenance costs	$/km per cycle
Transport process parameters (for each transport activity within the lifecycle and assessment case)	Transport vehicle emissions	t CO2-e per 1 tonne moved 1km (ARRB to reference data for each vehicle type)
	Transport costs	$/km $/tonne.km
Use phase process parameters (for each assessment year and assessment case)	Traffic distribution	% heavy vehicles/ by default road types
End of life process parameters (for each pavement layer and assessment case)	End of life emissions	tCO_2-e (ARRB to reference data for each material)
	End of life disposal costs	$/tonne
	Disposal cost growth rates	%/year
	Fraction sent to landfill	Tonnes, or % of total within pavement layer (default=zero)
	Landfill-waste levy	$/tonne

Source: ARRB

Next, the input data was filtered for the identified 'essential' data that Main Roads needs to be able to enter the model to achieve results. Table 4.6 shows the filtered data categories that make up the TMR's essential input data requirements. This data does not form part of the reference dataset.

Table 4.6: Essential input data

Data category	Data type	Unit
Assessment basis	Name	Text
Pavement design parameters (for each pavement layer and each assessment case)	Name/description	Text
	Materials	Text: Selected from editable dropdown lists
	Layer thickness	Mm
	Mass of materials	Tonnes % of total within pavement layer
	Volume	M³
	CBR	%
Maintenance process parameters (for each pavement layer and assessment case)	Existing layer thickness removal	mm
	New layer constructed	mm
Maintenance process parameters	Maintenance intervals	Select maintenance years
	Maintenance types	Select maintenance type
	Maintenance triggers: IRI/NAASRA thresholds	m/km
Transport process parameters (for each transport activity within the lifecycle and assessment case)	Truck type	Select from heavy vehicle options
	Transport distances	Km for materials and trips

Data category	Data type	Unit
Use phase process parameters (for each assessment year and assessment case)	AADT	no
	AADT growth	%
	Speed (uninterrupted average)	Km/hr
	Roughness: IRI/NAASRA values	m/km

Source: ARRB

Finally, the input data was filtered for the identified 'optional' data which user can choose to enter (i.e. explanatory text) or are only used in certain types of assessments (e.g. sensitivity analyses).

Table 4.7 shows the filtered data categories that make up the 'optional' input data. This data does not form part of the reference dataset.

Table 4.7: Optional input data

Data category	Data type	Unit
Various categories throughout	Explanatory text/notes	Text
	Data sources	text
Sensitivity analysis parameters (high, central and low)	Carbon price	$/t CO_2-e
	Discount rates	%
	Waste disposal fees and levies	$/tonne
	Road alignments: • Curvature • Rise fall	 degrees/km m/km
	Speed	Km/hr
	Roughness: IRI/NAASRA values	m/km
Scenario analysis parameters	Resilience to climate shocks	Various
	Electric vehicle uptake	
	Changes in fuel standards	

Source: ARRB

4.4 CONSULTATION WITH LIKELY USERS OF THE MODEL

On 26 March 2020, the TMR and ARRB Project Leaders led two workshops with the potential end users of the sustainability assessment tool. The first workshop included members from the infrastructure planning group within TMR and the second included members from the detailed design group.

The planning group undertakes high level assessments of a project's feasibility (not usually at the level of specifying pavement designs and materials) and would likely rely on default reference data values built into the model. The model will, however, facilitate some options analyses at the pavement design level (by simply amending some of the pavement design variables), that may have previously beyond their internal capability.

The detailed design group is likely to be the key user of the model. The group have the knowledge, expertise, and the data available to run the model to generate results and explore its full capabilities.

4.5 DEVELOPMENT OF A REFERENCE DATABASE

The reference database consists of both 'reference' data and 'preferred data' and these will be built into the model as prefilled data fields. TMR users will have the option of overwriting the 'preferred' data fields (and are encouraged to do so if they possess more refined, project or assessment specific data) while the 'reference' data fields will be locked (only editable by an authorised administrator of the model) to ensure simplicity and reliability.

4.5.1 AIM

A reference database can be built into the sustainable pavement assessment model as the basis for assessing and comparing different innovative pavement technologies. The database will consist of generic input data that is tailored to the specific needs of TMR by including local QLD-specific data wherever possible. The reference database minimises the data sourcing and inputting required by TMR users (assessors) and ensures reliable, consistent and tailored sustainability assessment outputs. The database will be built up using ARRB's existing datasets as well as new (updated and locally specific) data as identified through research over time. The database will be continually developed and refined throughout the life of this project. As new data becomes available, there may also be an ongoing need to update the reference database and the model from time to time after completion of this project and during the model's implementation.

The database entry fields and preliminary input reference data are provided in Appendix D.

4.5.2 METHOD

The following method was used to develop a reference database:

1. Gap analysis:
   a. Comparing the identified data requirements (as described in section 4.3) with existing data from the previous and current NACOE project(s). This step identifies existing proven data and enables the compilation of a minimum viable dataset that can be used as baseline reference data.
   b. Identifying what data should be added, refined, removed or changed in order to maximise the quality and relevance of the model outputs. This step enables the development of a database that maximises the value of the model outputs for WA conditions.
2. Identifying the relevant data sources for QLD-specific data. Examples are data provided directly by TMR, from industry, research papers (including the NACOE program), existing infrastructure lifecycle assessment tools and databases, ATAP parameter values etc.
3. Obtaining QLD-specific data from various sources and populating a standard/ default reference database.

4.5.3 FINDINGS/OUTCOMES

Gap analysis

The gap analysis identified missing data, or data that could be refined for improved results, based on the steps described above, i.e. by comparing the identified existing data and the results from the data assessment to the model input data requirements. The outcome of the analysis is a recommended approach to fill the data gap with a combination of sourcing additional data and amending the model to match the available data.

Two proposed responses to the gap analysis including:

1. **Focus on the input data –** Data gaps may exist in the reference or customisable datasets. They can be addressed by requesting further information from TMR, reviewing research papers, using national or international benchmark data, or evidence-based assumptions.
2. **Focus on the assessment model –** Model shortcomings are inconsistencies between the model input data requirements and the available input data. Shortcomings can be addressed by designing the model (e.g. model scope, characteristics or calculations) so that it is able to work with the available data to produce useful results. This treatment adds some risk as it moves the model away from the already proven concept. The pro and cons will be assessed for any changes to the model scope or characteristics.

Filling the data gaps is the preferred solution compared to changing the model.

Comparing data requirements with existing data

This step identified existing proven data to enable the compilation of a minimum workable dataset that could be used as baseline reference data for this project. The existing reference data will be built into the MVP model. Further refinements may be possible during the development of the model.

Table 4.8 shows the data categories where existing proven data (including assumptions) is available and suitable for translation into a reference database. The table also identifies the default values (where there is a single value) and the source of the value.

Table 4.8: Existing reference data to be used

Data	Unit	Value	Source
Lane width	M	3.5m	Fanning et al. 2016
Lane length	Km	1km	Common measure
Number of lanes	No.	1	Common measure
Curvature	Degrees/km	20 ° /km (straight)	ATAP 2016 & Main Roads 2020b
Rise and fall	m/km	0m/km (flat)	
Discount rate	%	7% p.a.	Common measure
Material densities	kg/m^3	Available for common materials	Greenhouse Gas Assessment Workbook for Road Projects
Material emissions (mine to end of production)	tonnes CO_2-e per tonne of material	Available for common materials	Inventory of Carbon and Energy (ICE v2.0)
Vehicle emissions per tonne moved	tonnes CO_2-e per 1 tonne moved 1 km	Available for rigid / articulated truck	IS Materials calculator
IRI/NAASRA index development (annual change)	m/km	Various	ARRB's PLCC tool, or TMR's pavement deterioration model
Roughness (IRI/NAASRA) intervention threshold	m/km	IRI 2.0 56 m/km NAASRA 56 m/km	
Gross combined vehicle masses (all vehicle types)	kg	Various	ATAP 2016
Fuel consumptions (all vehicle types)	L/100km	Various	ATAP 2016
Vehicle operating cost model coefficients	No.	Matrices of coefficients for different road alignments	ATAP 2016
AADT growth (annual)	%	2.5%	Assumed
Fuel emission conversion factors	No.	Matrix (coefficient) values	ATAP 2016
Queensland Waste levy	$/tonne $/m3	$100/tonne	Queensland Government 2019c
Discount rates (sensitivities)	%	High: 10% Med: $7% Low: $4%	ABS 2019
Future traffic emission reduction factors (EV adoption scenario)	%	Various	ARRB analysis
Carbon price	$/tonne	High: $48.91 Med: $30.57 Low: $12.22	ATAP 2019 (unpublished)

Source: ARRB

Identify what data should be added, refined, removed or changed in order to maximise the quality and relevance of the model outputs.

This step enables the development of a database that maximises the value of the model outputs for QLD conditions. Table 4.9 identifies the reference data which could be refined if better data can be identified.

Table 4.9: Identified data for refinement

Data	Unit	Comment
Materials densities	Kg/m^3	Need to source material densities for a small number of innovative, or less common materials
Material emissions (mine to end of production)	tonnes CO_2-e per tonne of material	Need to source material emissions for a small number of innovative, or less common materials
Emissions per tonne moved (other vehicles)	tonnes CO_2-e per 1 tonne moved 1 km	Currently limited to two material transport truck types (rigid and articulated)
Haulage costs (all materials)	$/km, $/tkm	Currently assuming a single haulage cost for all materials. Assumed data may not be representative of QLD costs
Construction costs	$/lane.km	Assumed data may not be representative of QLD costs
Maintenance costs per maintenance cycle	$/lane.km	Assumed data may not be representative of QLD costs
End-of-life disposal costs per maintenance cycle	$/lane.km	Assumed data may not be representative of QLD costs
Waste levy annual change	%	Assumed data may not be representative
Gross combined vehicle masses (all vehicle types)	kg	Sourced data may not be representative of QLD vehicle masses
Fuel consumptions (all vehicle types)	L/100km	Sourced data may not be representative of QLD vehicle fuel consumption
Future traffic emission reduction factors (EV adoption scenario)	%	Assumed data may not be representative
Carbon price	$/tonne	Sourced data may not be representative of QLD
AADT (growth)	%	Assumed data may not be representative

Source: ARRB

Identify the relevant data sources for QLD-specific data.

ARRB will continue to source more refined and update the reference database using the following sources:

- data provided directly by TMR, such as benchmark cost data and average haulage distances
- industry, including construction contractors who are familiar with the on the ground processes.
- research papers (including the NACOE program)
- existing infrastructure lifecycle assessment tools and databases
- existing data sources, such as ATAP parameter values, project evaluation and business case guidelines, etc.

Obtain best available reference data from various sources and populate a standard/ default reference database

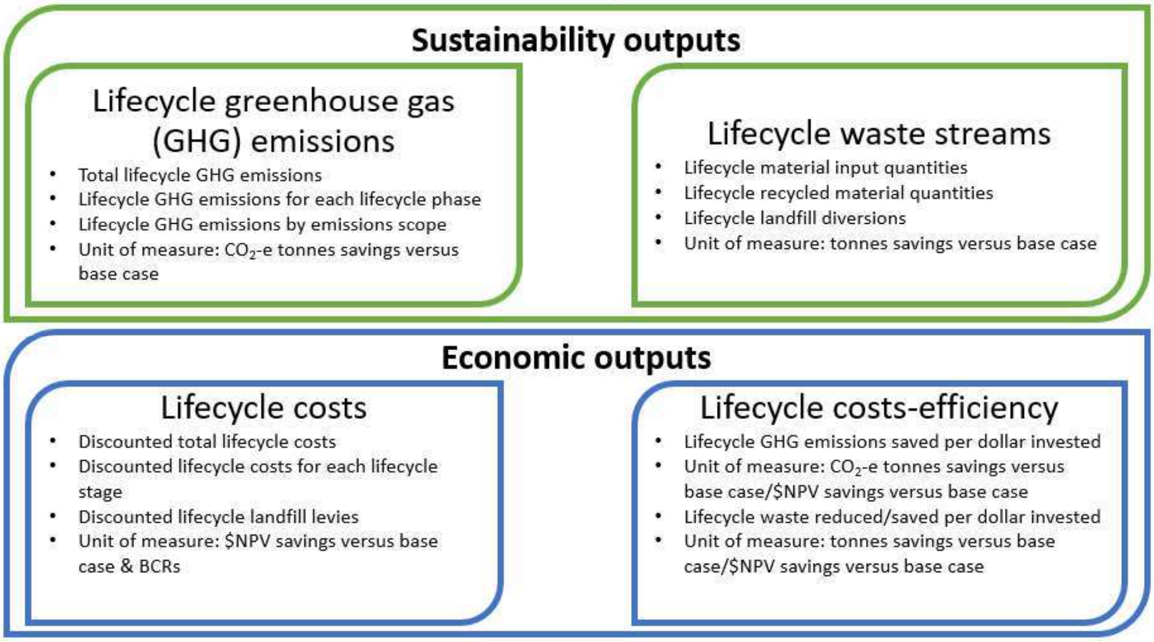
This is an ongoing task that will be completed in parallel to the model development and user enhancements.

5 KEY MODEL OUTPUTS

5.1 KEY OUTPUTS

The model will produce comparative sustainability and economic outputs, as presented in Figure 5.1Figure 3.2.

Figure 5.1 Sustainability and economic outputs



Source: ARRB

Section 5.2 shows sample outputs and figures that could be generated. These are not samples are not comprehensive of the model's output capabilities.

5.2 SAMPLE OUTPUT TABLES AND FIGURES

The following sample output tables and figures have been generated for illustrative purposes. Values included should not be referenced.

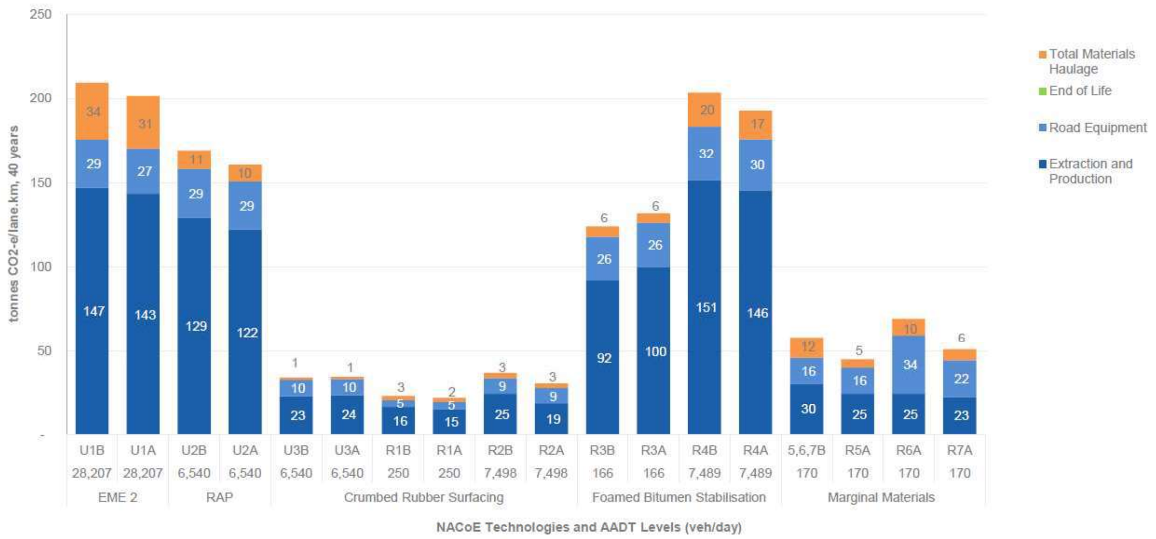
Table 5.1: Sample output: Total emissions by lifecycle phase

Total Emissions [tonnes CO_2-e/lane.km – lifecycle assessment period (x years)]			
Lifecycle Stage	Output component	Base pavement design	Alternative pavement design
Extraction and Production	Embodied Energy - Construction	12.03	6.15
	Embodied Energy - Maintenance	18.46	18.46
	Sub-total	30.49	24.61
Construction	Construction - Equipment Emissions	8.60	8.60
	Construction - Haulage Emissions	9.25	2.47
	Sub-total	147.85	11.07
Use	Use Phase - Vehicles	2,613.63	2,617.04
	Sub-total	2,613.63	2,617.04

Maintenance	Maintenance - Equipment Emissions	6.95	6.95
	Maintenance - Haulage Emissions	2.31	2.31
	Sub-total	9.26	9.26
End of Life	End of Life	-	-
	Material Haulage - to Landfill	-	-
	Sub-total	-	-
Total Materials Haulage		11.56	4.78
Total Lifecycle Emissions		2,671.23	2,661.97

Source: ARRB

Figure 5.2 Total emissions by pavement options (excluding use phase)



Notes:

- Refer to Table 5.1 for NACoE pavement technology names and pavement designs evaluated.
- The A suffix indicates the alternate NACoE technology and the B suffix indicates the base case technology.
- Indicative AADT levels per lane-km are provided along the x-axis. Note that on urban roads 2 lanes were assumed on each carriage-way.

Source: ARRB 2019

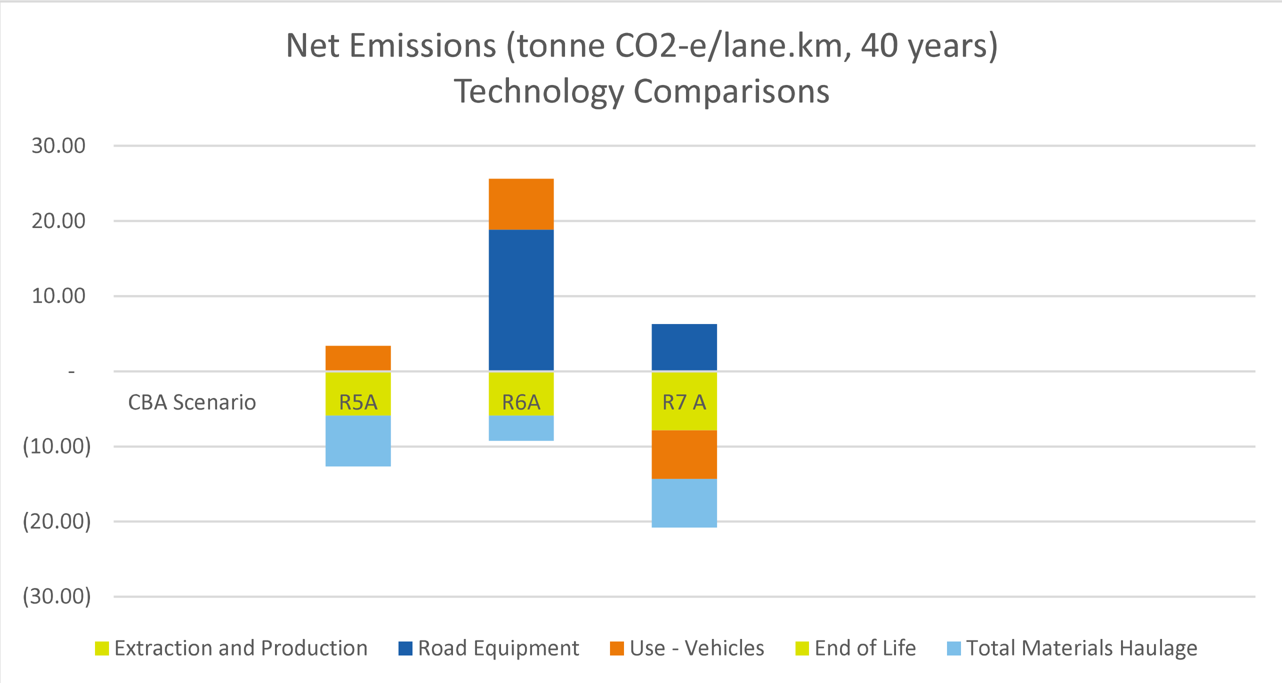
Table 5.2: Sample output: Net emissions by lifecycle phase

Net Emissions [tonnes CO_2-e/lane.km – lifecycle assessment period (x years)]		
Lifecycle Stage	Output component	Alternative pavement design vs base case (-ve value denotes an emissions savings)
Extraction and Production	Embodied Energy - Construction	-5.88
	Embodied Energy - Maintenance	-
	Sub-total	-5.88
Construction	Construction - Equipment Emissions	-
	Material Haulage - to Construction	-6.78
	Sub-total	-6.78
Use	Use	3.40

Maintenance	Maintenance - Equipment Emissions	-
	Material Haulage - to Maintenance	-
	Sub-total	-
End of Life	End of Life	-
	Material Haulage - to Landfill	-
	Sub-total	-
Materials Haulage	Sub-total	-6.78
TOTAL	Net Emissions	-9.26

Source: ARRB

Figure 5.3 Sample output: Net emissions by lifecycle (excluding use phase)



Source: ARRB

Table 5.3: Sample output: Scope emissions by lifecycle phase

Emissions by scope [tonnes CO_2-e/lane.km – lifecycle assessment period (x years)]				
Emissions scope	Output component	Base pavement design	Alternative pavement design	Alternative pavement design vs base case (-ve value denotes an emissions savings)
1. Direct emissions from owned or controlled sources	Construction - Equipment Emissions	8.60	8.60	-
	Material Haulage - to Construction	9.25	2.47	-6.78
	Maintenance - Equipment Emissions	6.95	6.95	-
	Material Haulage - to Maintenance	2.31	2.31	-
	Material Haulage - to Landfill	-	-	-

	Sub-total	27.11	20.33	-6.78
2. Indirect emissions from the generation of purchased energy Indirect emissions from the generation of purchased energy	On-site energy use (e.g. diesel power)	To be derived from Construction and Maintenance - Equipment Emissions		
	Sub-total			
3. Indirect emissions (not included in scope 2) that occur in TMR's value chain	Embodied Energy - Construction	12.03	6.15	-5.88
	Embodied Energy - Maintenance	18.46	18.46	-
	Use	2,613.63	2,617.04	3.40
	End of Life emissions	-	-	-
	Sub-total	2644.12	2641.65	-2.48
TOTAL		2,671.23	2,661.97	-9.26

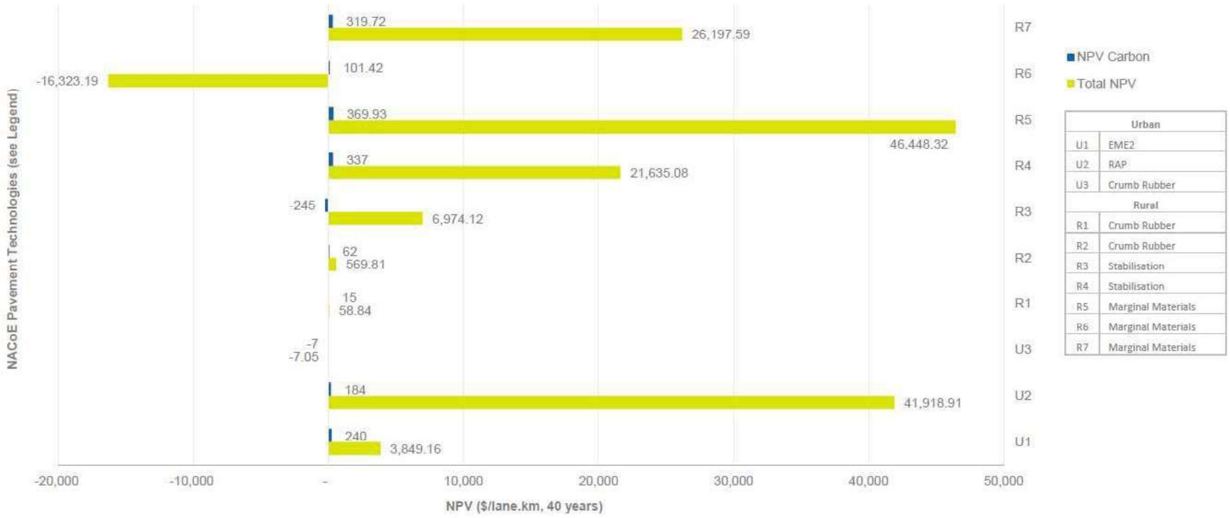
Source: ARRB

Table 5.4: Sample output: Cost benefit analysis

Cost Benefit Analysis [$/lane.km - lifecycle assessment period (x years)]			
CBA analysis	Discount rate	Base pavement design	Alternative pavement design
NPV	4%	46,430.58	- 68,947.00
	7%	46,448.32	- 16,323.19
	10%	46,456.21	9,384.88
Marginal BCR	4%	- 0.01	- 0.00
	7%	- 0.01	0.01
	10%	- 0.01	- 0.02
PV Carbon	4%	352.18	- 56.77
	7%	369.93	101.42
	10%	377.82	190.94

Source: ARRB

Figure 5.4 Sample output: Lifecycle NPV and carbon price outputs



Source: ARRB 2019

Appendix E provides some guidance on how to use cost benefit analysis results in decision making.

6 ASSESSING WHETHER EXISTING PRODUCTS COULD MEET THE USER NEEDS

The previous sections outlined an understanding the of user requirements, the capabilities to address these and an outline of the proposed model scope. The following analysis shows how the proposed model is unique to another lifecycle assessment tools. This combination of having a model scope that meets the users' particular needs and being unique justifies the investments that TMR is making into the development of the model.

ARRB examined 16 lifecycle assessment (LCA) tools including:

- three of the most widely used generic commercial LCA products
- three Australian road infrastructure LCA tools
- 10 international infrastructure LCA tools and databases.

6.1 SUMMARY

There is a broad range of lifecycle assessment (LCA) tools and databases available for road infrastructure assessments. Some of these tools are available for purchase or via subscription, while others were available for free. While each have specific strengths, none fully catered for all the user requirements as identified in section 2. The key areas where the proposed Sustainability Assessment Tool stood out against comparable LCA tools were:

- Allows for detailed and innovative pavement designs
- Flexibility to enter user-defined assessment and process parameter to generate refined results
- Inclusion of the use phase in the pavement's lifecycle
- Incorporates Australian and Queensland reference data
- Concurrently evaluates economic and sustainability outcomes (including recycling and waste outputs).

A table of results is presented in Appendix C.

6.2 COMMERCIAL LCA PRODUCTS

The three commercial products are widely accepted, easy to use and generate generic lifecycle analyses covering a variety of industries and applications. They are not however, tailored to the complexities of road pavements nor Australian materials and processes, with limited data on recycled pavement materials. Each are available on a subscription basis.

6.3 AUSTRALIAN ROAD INFRASTRUCTURE LCA TOOLS

The three Australian road infrastructure LCA tools reviewed were:

- The IS Materials Calculator (v 1.2 and v 2.0) (ISCA)
- The Carbon Gauge Tool (TAGG)
- The Carbon Estimation Reporting Tool (TfNSW).

The proposed sustainability assessment tool has similarities, and crossovers, with the IS Materials Calculator, but is also unique in its scope and flexibility.

The IS Material calculator is a support tool for the IS rating scheme which evaluates environmental impacts on projects. The IS Material Calculator calculates embodied environmental impact factors for the 'cradle to manufacturer gate' for a wide range of typical construction materials. It uses best available data from the

Australian Life-Cycle Inventory database (AusLCI) and its shadow database. While the IS Materials Calculator is useful for many applications, it has the following limitations:

- Lacks flexibility to enter non-standard, or innovative, pavement materials or designs, with pavement selection limited to predefined pavement types and materials (i.e. drop-down menus)
- Not tailored for local assessment (i.e. does not allow for the use of local, or state specific emissions factors (where relevant data may be available)
- Has a narrow definition of the use phase within the pavement's lifecycle, i.e. it does not include the on-road vehicle emissions, road user costs and ability to assess how design, maintenance and alignment options affect use phase emissions
- The transport component only covers material haulage from the manufacture's gate (i.e. extraction & production to construction site)
- Does not incorporate cost benefit analysis comparing the base case to alternative case i.e. does not allow for simultaneous cost evaluations
- Does not capture waste-recycling streams throughout the pavement lifecycle.

The Transport Authorities Greenhouse Group (TAGG) developed the Carbon Gauge Workbook to provide road designers, builders, managers and operators with a means of consistently estimating greenhouse gas (GHG) emissions at the key stages of construction, operation and maintenance.

The workbook is designed to enable a consistent methodology for the assessment of significant emission sources, estimation of GHG emissions and to provide a better understanding of how GHG emissions can be reduced.

The Carbon Gauge Tool is an Excel-based, macro-enabled spreadsheet of the GHG calculation methods described in the workbook. The tool is useful in a number of applications but has the following limitations:

- Lacks flexibility to enter non-standard, or innovative, pavement designs, with pavement selection limited to predefined pavement types and materials (i.e. drop-down menus)
- Not calibrated for locally specific conditions and emissions factors
- Does not separate embodied carbon and haulage emissions
- Does not include ability to calculate 'use' phase emissions
- Explicitly excludes decommissioning (end-of-life phase) – although it acknowledges that this rarely occurs
- Does not include an economic cost analysis component
- Does not capture waste-recycling streams throughout the pavement lifecycle.

The carbon gauge tool may still be a useful for sourcing input data to feed into the sustainable assessment tool. Where possible ARRB will assist users of the tool by pre-populating a reference database with input data. Some of this data may be sourced from the carbon gauge tool or its reference database.

Similar to the IS Materials Calculator and the Carbon Gauge tool, Transport for NSW's Carbon Estimation Reporting Tool (CERT) is limited in its materials and lack the flexibility, making it difficult to differentiate pavement designs.

6.4 INTERNATIONAL LCA TOOLS AND DATABASES

None of the international tools were considered appropriate because they were linked to international data sources. Two tools stood out as having similar scope and analytical depth as the proposed sustainability assessment tool.

The Asphalt Pavement Embodied Carbon Tool (asPECT) is a UK-based whole-of-life greenhouse gas emissions tool for asphalt used in highways. asPECT provides detailed guidance on the data required for assessment and how to calculate emissions for each component considering the CO2e impacts of building and maintaining a road pavement, from sourcing raw materials and laying mixtures to maintenance through periodic interventions to ultimate deconstruction.

However, input information regarding asphalt production is limited and it is not particularly user friendly, i.e. it requires asphalt mix specifications and origin of energy used during asphalt production. Difficult for non-specialist to acquire reliable calculation results or even rough estimates.
Comparison between asphalt pavements and cement concrete pavements on the same basic calculation rules, is not possible.

The US-based Pavement Lifecycle Assessment Tool for Environmental Economic Effects (PaLATE) v 2.0 tool provided lifecycle environmental effects and costs related to the road design, initial construction, maintenance, plant use and project costs, and was one of the few reviewed pavement LCA models that incorporated economic evaluations. However, due to the source data, the tool is only applicable for use in US conditions.

7 CONCLUSION

The model scoping study outlined an approach to address a capability gap. This approach involves developing a user-friendly sustainability assessment tool that enables consistent and reliable quantification and comparison of lifecycle sustainability and economic impacts of pavements, by demonstration of a minimal viable product (MVP) followed by model enhancements and then an improved (front-end) user-interface.

The model scoping exercise involved:

- Reviewing the user requirements for a pavement lifecycle assessment tool (from a policy, stakeholder and IS ratings perspective)
- scoping the minimum viable product model
- determining the necessary input data requirements
- obtaining the views of likely users of the model in terms of appropriateness and accessibility of the necessary input data
- building relevant reference datasheets
- reviewing other LCA tools commercially available
- outlining the key model outputs.

The user requirements review documented TMR's sustainability assessment needs. These needs were mapped against a list of model capabilities to inform a minimum viable product model scope. This review demonstrated a clear understanding of the policy drivers and internal project assessment needs and reporting requirements that TMR's builds into its everyday decision making. Documenting TMR's needs and mapping these against the proposed model's capability provided clarity and transparency of the direction of the model scope and its development.

Key attributes of the model scope include:

- Compares pavement lifecycle GHG emissions, waste and costs for a base pavement design against an alternative pavement design
- Assessment over a user-defined lifecycle period
- Pavement design (technology) or project/route-specific assessments.

The proposed model's capabilities are unique to any existing lifecycle assessment model. Its uniqueness is based on its flexibility, incorporation of vehicle usage in the pavement lifecycle, economic evaluations, Queensland and Australian specific data, and ability to compare innovative pavement designs, materials and processes.

The proposed sustainability assessment model will require an array of specific customisable and non-customisable input data to generate useful results. The input data assessment identified, characterised and described the data needed to run the model. It also sought identify existing datasets and gaps, or data that could be further refined to QLD-specific analyses.

Building a reference database is an ongoing process which ensures that TMR users only need to input a minimum amount of customisable data (although they have the flexibility to overwrite the data if more granular, locally or project specific data is available). It also ensures consistent and reliable results.

Finally, the model scoping document produced a sample of the kind of comparative sustainability and economic outputs the model can produce.

ARRB's view is that the proposed model scope meets a number of TMR's operational and policy needs, and TMR has ready access to the essential data needed to run the proposed model. This finding supports the development a proof of concept Excel-based model to enable consistent and reliable lifecycle sustainability and economic assessments of innovative pavement designs. This proof of concept model will be based on a minimum viable product (MVP) approach – one that meets TMR's basic needs and allows for further testing and enhancements thereafter.

At the time of finalising this document, the MVP model had been well developed and was undergoing user testing.

REFERENCES

Australian Transport Assessment and Planning (ATAP) Guidelines Steering Committee, 2016 *Australian Transport Assessment and Planning (ATAP) Guidelines: PV2 Road Parameter Values*, Commonwealth of Australia, Canberra

Council of Australian Governments 2020, *Response strategy- Phasing out exports of waste plastic, paper, glass and tyres*, report, Council of Australian Governments, Australia.

Department of Transport and Main Roads 2020, Queensland Transport Strategy, Queensland Government, QLD, viewed 25 April 2020, <https://www.tmr.qld.gov.au/queenslandtransportstrategy>.

Dilger, A, Riley, C, Bengtsson, J, 2013 *Supporting document for greenhouse gas assessment workbook for road projects*, Transport Authorities Greenhouse Group, Sydney.

Fanning, R, Veith, G, Whitehead, M and Aumann, P, 2016 *Guide to Road Design Part 3: Geometric Design*, Austroads, Sydney.

Gearheart 2020, *How to Build a Minimum Viable Product (MVP)?* viewed at 25 February 2020 at <https://gearheart.io/blog/how-build-minimum-viable-product-mvp/>.

Greenhouse Gas Protocol 2014, *Greenhouse warming potential values*, World Resources Institute, Washington, DC, USA, viewed 25 February 2020, <http://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf>.

HR Capitalist 2020, *Minimum viable product in the world of HR*, viewed 25 February 2020 at <https://www.hrcapitalist.com/2019/02/minimum-viable-product-and-hr.html>.

Infrastructure Sustainability Council of Australia 2020b, *Infrastructure sustainability*, viewed 18 February 2020 at < https://www.isca.org.au/Who-We-Are/Infrastructure-Sustainability>.

NACOE 2020, (unpublished), *Recycled materials in Queensland's roads infographic,* ARRB, VIC, Australia.

Queensland Government 2017, *Pathways to a clean growth economy*, report, Queensland Government, QLD, Australia.

Queensland Government 2019a, *Waste Management and Resource Recovery Strategy,* report, Queensland Government, QLD, Australia.

Queensland Government 2019b, About Queensland's waste levy, webpage, Queensland Government, Brisbane, Qld, viewed 21 June 2019, <https://www.qld.gov.au/environment/pollution/management/waste/recovery/disposal-levy/about/overview>.

Queensland Government 2019c, Levy rates, webpage, Queensland Government, Brisbane, Qld, viewed 21 June 2019, <https://www.qld.gov.au/environment/pollution/management/waste/recovery/disposal-levy/about/levy-rates>.

World Resources Institute 2019 *Greenhouse gas protocol: FAQ*, viewed 17 December 2019 at <https://ghgprotocol.org/sites/default/files/standards_supporting/FAQ.pdf>.

APPENDIX A PROJECT METHOD - NEXT STEPS

A.1 STEP 2: MODEL ENHANCEMENTS

Upon confirmation of scope (Step 1 decision point), developing model enhancements within the Excel platform would include:

- Opening up the existing P106 model input assumptions and new user input categories (e.g. materials processing) to user-input. This would allow for customisable technology-specific assessments, e.g. EME2 with crumb rubber modified asphalt binder.
- Enhancing the existing P106 model to allow for project specific lifecycle CO_2 and economic cost assessments. This would involve incorporating new project specific input fields, e.g. road length, number and width of lanes, location compared with source materials and disposal, use of construction vehicles and machinery, etc.
- Refining the existing P106 model to allow Main Roads users to compare lifecycle CO_2 and economic cost for different pavement options (on a technology or project basis). This would involve developing/updating model outputs tables to show lifecycle CO_2 impact and economic costs for a range of options, based on user-entered data. This refinement would allow for comparisons between multiple options (limited only by the ability to enter necessary pavement design input data) and would help identify a preferred pavement option for a given project.
- Enhancing the existing P106 model to provide default input values where project specific information is not available. This would involve assessing input data requirements and generic and project-specific data availability, and building default value tables, e.g. sample pavement parameters, emission factors and costs, maintenance frequencies, ATAP parameters, etc. Sample pavements would include (at a minimum): EME2, crumb rubber pavement applications and equivalent standard pavement types, and others as identified by Main Roads.
- Testing the robustness of the new model, calculations and outputs for quality and sufficiency. This would involve comparing results to benchmark data (research), sensitivity testing (analysis) and consultation with Main Roads pavement engineers.
- High level investigation and scoping of user-interface delivery options (e.g. Excel, web-based, other).
- Considering the hosting and licensing options for further investigation in step 3.

Outputs:

- A proof of concept sustainability assessment model for innovative pavements built in an Excel platform
- Documentation of model development method and testing results
- Consultation with Main Roads on preferred user-interface delivery options, hosting and licensing arrangements (HOLD POINT – Confirmation of scope for steps 3 and 4).

A.2 STEP 2B: MODEL ENHANCEMENTS

Investigate model enhancements for feasibility, development options, costs, timing and methods, including (shown in preference order[6]):

1. Optimisation of pavement designs to achieve minimal lifecycle GHG emissions and cost (and, if feasible, other factors such as waste, water, energy use)
2. Other airborne pollutants as per GRI Standard 305 emissions reporting (PM10s, VOCs etc.)
3. Enviropoints (an IS-specific measure of environmental impacts that go beyond GHGs)

[6] WARRIP and NACOE Project Managers discussed and agreed on enhancement priorities on Thursday 16 April.

4. Water use (IS credit Wat-1)
5. Energy usage – kWh output for energy use (a component of IS credit Ene-1).

Develop and test agreed model enhancements.

Outputs:

- Advice on feasible model enhancements options
- An enhanced model and project report.

A.3 STEP 3: USER-INTERFACE DEVELOPMENT

Specific details to be scoped separately following completion of step 1 (scoping model enhancements) and refined following completion (or near completion) of step 2 (developing the proof of concept).

Developing a user-friendly interface could involve:

- considering the data input and processing needs, suitable IT-platforms, IT development, testing and implementation and recommending a preferred approach.
- Developing a user manual / instruction for use.
- Detailed development of hosting approach and licensing agreement.

Outputs:

- Documentation of method and findings developing a user-friendly model interface
- A user manual for the model
- Documented hosting and licensing arrangements.

A.4 STEP 4: INVESTIGATE OPPORTUNITIES TO EXTEND MODEL

Specific details to be scoped separately following completion of step 1 (scoping model enhancements) and refined following completion (or near completion) of step 2 (developing the MVP model).

Extending the model could involve:

- defining the scope of included infrastructure (e.g. bridges, culverts, barriers, drainage, signage, lighting, off-road paths)
- determining the construction/maintenance materials and activity components, through research and interview with structural engineers
- identifying the carbon emissions factors for relevant materials and activities, through review of ISCA, carbon gauge models and other Australian and international sources.
- identifying economic cost estimates for materials and activities, through review of economic appraisal guidelines, business cases and benchmark data
- incorporating into the lifecycle emissions and costing model
- testing validity of the updated model, including assumptions, e.g. that 'use phase' costs and emissions occur only on the road pavement, i.e. they are not attributable to other road infrastructure.

Outputs:

- Documenting the scope, method and recommended approaches for extending the model/application
- An extended model based on the approaches taken in step 3.

APPENDIX B TMR WORKSHOP FEEDBACK AND RESPONSES

Topic	Stakeholder comments SS= Stephen Hulme PB=Peter Bryant PP= Philip Pearson LD= Louise Dutton	Response
Assessment Period	• We will commonly design pavements as low as 10-20 years (SH) • Agree with 40 year default. This should allow at least one rehab treatment to be undertaken during the assessment period. Beyond 40 years the estimates of traffic and pavement performance are likely to be very uncertain (PB)	• Model will allow for users to define the assessment period. • Use 40 year default period
Road alignment	• Thinking about rise and fall – from an economic perspective will the tool be able to model cost sensitivity? (SH) • Does it matter if it is uphill / downhill or a combination? (PP) • Use 'longitudinal grades' instead of 'rise and fall' and 'horizontal alignment' instead of 'curvature' (PP/SH)	• Users will be able to input a range of road alignment values (in line with the ATAP VOC alignment options). Cost sensitivity can be modelled by changing alignment parameters. • Road alignment impacts VOCs and use phase emissions, but broader earthworks are excluded from the GHG and cost calculations • Model calculated use phase emissions uses a matrix of default multipliers (from ATAP) for different vertical and horizontal grades. Model allows for multiple road segments that have different road alignments. • Replace terminology: 'longitudinal grades' instead of 'rise and fall' and 'horizontal alignment' instead of 'curvature'
Assessment segments	• Will there be capability to break a pavement into sections and have the tool calculate a cumulative total of all sections. This will allow for projects with varying pavement type (some standard unbound granular and some foam bitumen stab). Also to enter different grade lines and widths for sections (LD)	• Model allows for multiple road segments with functionality to generate results by segment and by total project.
Location/regional definitions Flexibility for differences between districts	• I expect there may be as much variation within districts as across districts (SH)	• Users are able to enter in values for cost and emissions to reflect local factors otherwise typically Australian generic factors would be there and the ones accepted by ISCA and industry. • As emissions reporting becomes more common and/or major producers are required to get an EPD more refined local data may become available.
Usefulness of Urban/ rural split	• Unlikely to be helpful. Would speed environment be more useful? 60km/hr with traffic lights and intersections vs 110kh/hr highway. The acceleration and deceleration of trucks can chew through fuel (PP)	• Users should be able to provide AADT/traffic distributions, so urban/rural road categorisations unlikely to be helpful. • Speed environments, road alignments and interrupted vs uninterrupted traffic flow (ATAP equations) is needed.
Usefulness of road categories	• Probably unhelpful. Estimated traffic volumes (AADT) and %HVs should be data that is easily accessible (even in the Options Analysis / Business Case stage) (PP). • I would prefer to have a blank field that needs someone to think about rather than a pre-filled option that needs to be overridden (SH).	• The use phase needs AADT and %HVs data. The model contains reference tables with a range of default traffic distributions if that is unknown. Users can overwrite with locally specific data if available.
Pavement layers naming conventions.	• Split prime and seal (SH)	• Split the prime and seal into different layer options. • Include options to select the layer name based on a list of layer names.

Topic	Stakeholder comments SS= Stephen Hulme PB=Peter Bryant PP= Philip Pearson LD= Louise Dutton	Response
Flexibility to incorporate different pavement structures and/or layer naming.	• This is a typical 'asphalt' structure. There are many more layer titles in different pavements. Other pavement layers to consider include, subbase (lower and upper), upper zone embankment, embankment fill, spray seals, insitu stabilised subgrade, insitu stabilised subbase, insitu stabilised base, working platform, subgrade treatment and so on (PP) • Agree, but would see insitu stab as a material treatment rather than a layer (SH) • Why not just make it Layer 1, Layer 2, Layer 3… etc then the material type or treatment can be selected for each layer. The layer name doesn't really matter (PB)	• Include options to define pavement layer names. • It does not have to be predefined or pre-named. Can have default values or options from a drop down menu with the flexibility to enter own data. • Layer names not critical to calculations as long as the pavement layers are in the right order (i.e. top to bottom).
AADT	• I would prefer to have a blank field that needs someone to think about rather than a pre-filled option that needs to be overridden (SH)	• Users can enter custom traffic data or select from a range of default traffic distributions, noting that estimated traffic volumes (AADT) and %HVs should be data that is easily accessible in the Options Analysis / Business Case and detailed planning stages. • AADT is an input for the calculation of the use phase emissions (and potentially pavement deterioration depending on the approach taken)
Materials (general)	• Must be flexible to add new materials as required, but avoid that unverified values are used or entered	• Capability to add new materials included • Need rules/guidance around identifying/assuming material properties, e.g. densities, emissions factors – to be included in user guidance document (2020/21 program)
Material Categories	• The materials library should reflect the materials classifications that we use rather than generic terms (SH) • Agree, this is very important in making the tool user friendly and to avoid errors (PB)	• Materials database includes the material ingredients to make up a pavement design/mix. Materials database is comprehensive for standard and innovative materials currently used. Future expansion and refinement of the materials database is reliant upon having the materials emissions factors and densities. These parameters are not available for all possible materials. • Note that the formula needs to be sensitive to how it is sorted to make sure it is not looking up wrong density, emissions and/or cost factors.
Asphalt mixes with other materials	• I assume if we specify asphalt we don't also have to call up the constituents? How do we model asphalt with Glass? (SH). • Ideally should have a single material (asphalt) in which you can nominate the proportions of different materials – such as glass, RAP, crumbed rubber etc (SH).	• Model includes some standard/common mixes but users will need to identify the constituents to develop innovative pavement designs, such as crumb rubber asphalt, or asphalt with glass.
Additional Materials – EME 2.	• EME2? (SH)	• We currently do not have an EME2 emissions factor as a material only as bitumen and aggregate and assumptions regarding voids. The construction emissions were subject to the estimated number of lifts/processes.
Additional Materials – PMB vs. Other Materials	• PMB vs. straight bitumen vs multigrade? (SH) • We don't really buy asphalt based on its binder content. Would probably simplify (SH)	• Users can select the appropriate binder based on the pavement design • Note that the PMB binder differences may be in the performance. In P106 Part 1 they were considered equivalent or not sufficiently different to warrant different deterioration profiles (years of maintenance). In the past we have assumed a similar performance, and/or allow for a performance scaling factor if better performance is known. i.e. deterioration is X% slower when using a better performing material or binder… User would have to define x (and justify this with evidence for ISCA ratings) • Generally, the modelling considers items which are materially significant. The additives may not be sufficiently materially significant. • Any differences in costs should be captured in the data entry fields – for construction costs.

Topic	Stakeholder comments SS= Stephen Hulme PB=Peter Bryant PP= Philip Pearson LD= Louise Dutton	Response
Additional Materials – Crumbed Rubber	• Just the Crumb? Or Binder? (SH)	• Should allow for both applications of the material. • Note that the crumbed aspect is materially significant and thus quantified in the modelling. • The ISCA v2.0 had only one crumbed rubber mix which has been build into the model.
Additional materials – fly ash / slag	• Fly Ash / Slag? (SH)	• Fly ash and slag emissions factors from the ISCA 2.0 have been built into the model • The tool would be limited by the available emissions factors and data.
Additional materials – Fine and coarse aggregate.	• Define coarse and fine. Would prefer that we use the terminology that is well understood on TMR projects (SH) • Rockfill / Drainage layer. • Type 1/2/3/4 – including subtypes as each subtype will have a different cost. • Select backfill etc.	• Model uses best available materials data (emissions factors) and definitions – terminology is typically used and easy to understand.
Additional materials – spray seal options.	• More options need to be provided in this table. For example, spray seals have a number of options that would all have a different rating: prime, primer seal, C170 seal, C320 seal, PMB seal, crumbed rubber seal, emulsions. Base: asphalt, granular (Type 1, 2 and 3s), cement stabilised, lightly bound, foamed bitumen stabilised, insitu cement stabilised, insitu foamed bitumen stabilised, unreinforced concrete, reinforced concrete. • Subbase: granular (Type 1, 2 and 3s), cement stabilised, lightly bound, foamed bitumen stabilised, insitu cement stabilised, insitu foamed bitumen stabilised, lean mix concrete. • Some other pavement materials that need to be considered include rock fill and geo-synthetics. (PP)	• Included all aggregate, binder, additive and other materials that we can source the relevant emissions data. • New research may be required to fully satisfy the complete list of materials (i.e. that is beyond the current project scope). • Each layer you can specify what is in each layer and what percentage. • Insitu maintenance processes to be included in the model's capabilities • A clear scope diagram would show where the boundary of the assessment starts and where it finishes. i.e. . Excluding embankments etc.
Additional Materials Categories – Hybrid Materials.	• Need to consider how you would model a 'hybrid' material. For example, insitu foamed bitumen base that incorporates 100mm Type 2.1 granular overlay: would this be modelled as 100mm granular + insitu foamed bitumen stabilised 300mm deep? Another example is a plant mixed material such as concrete – the aggregates and sand could be imported from a variety of different sources and batched onsite. Will the assessment tool allow for this situation? (PP)	• The first example sounds like an innovative pavement design which is what the model is designed for (i.e. we can split materials over different layers) – the second can be dealt with by calculating embodied and haulage emission on a material basis rather than by layer. • Haulage will be set up on a material basis rather than a layer basis. • Build in the flexibility for multiple sources of a single material like sand.
Materials and treatments	• Treatments of existing materials, like in situ stabilisation of an existing subgrade material (PB)	• In situ treatments in the construction/maintenance phase will be built in
Processes	• Will machinery / plant operations be considered in this? Or will these be considered in the materials calculation? For example, insitu stabilisation can require spreader, stabiliser, water carts, rollers, grader. Will these plant operations be captured in the materials calculation (PP) • Will there be capability to calculate GHG for in-situ stabilised pavements that involve energy inputs in terms of stabilisation but not imported material (LD) • This needs to be included in materials IMO (SH)	• Plant production of materials (i.e. sifting and screening) is captured in the material emissions (extraction and production phase). Machinery, including insitu stabilisation, emissions are captured in construction emissions. Model includes construction and maintenance processes, but at a fairly high level. • Note P106 Part 1 – used benchmark values based on the greenhouse gas workbook and adjusted according to the number of processes and lifts. New model will refine/enhance this approach.

Topic	Stakeholder comments SS= Stephen Hulme PB=Peter Bryant PP= Philip Pearson LD= Louise Dutton	Response
Haulage Vehicle Types	• Depends – but typically it will be limited to what is allowed on the road (for example, Type 2 road train routes would probably use Type 2 road trains). • It will also be dependent on the material type (asphalt doesn't get transported in-side tipper and concrete can come in an agitator for example), required delivery rate and site access. • I would suggest including a wide range of HV options and then allowing the Designer to choose the ones applicable for each material type. The Designer could also assign a proportion to how much of that material would be carted using the HV type (PP). • Need at least rigid trucks, semi-tippers, tuck and dogs, side tippers, multiple types of Agis. Gets even more complicated if you consider PBS options. What about site transport – for example Moxys? (SH)	• Up to 6 HV haulage vehicle type to be included. Users can select for different materials. • PBS vehicles not included at this stage. • ISCA v2.0 calculator only has two vehicle types. • Cost factors need to be entered by the user (default values are pretty rough, i.e. 10c per tonne km) • On site transport included in the construction and maintenance phases
Haulage Distances	• This will be typically pretty easy / quick google map calculation – the Designer would know locations of material suppliers • The difficulty will be in areas where there are a number of suppliers (that is, SEQ) – in this situation the Designer would need to take a best guess. • Suggest this be a designer input and be material dependent (different sources for different material types) (PP)	• Haulage distances are for each material (previously on a layer basis). • Users need to specify haulage distances on a project basis. Assumptions can be made for technology based assessments similar to those conducted under the P106 project. • Users should overwrite default haulage distances where project specific knowledge is available. Noting that haulage is a significant factor affecting both emissions and emissions reductions – there would need to a degree of accuracy in the inputs and/or consistency in the methods – i.e. the model is only as good as the inputs and assumptions. • Users need to specify if single or return trip and assumed loadings. • Note: Louis Bettini (MRWA) suggested that if users deviate from accepted default values they should provide evidence to support the change – this will be a requirement for ISCA ratings and is good practice elsewhere. We should build this into the guidance.
Haulage costs	• Set default as 10 - 15 cents / t. km, but allow an override function (SH)	• Default haulage cost set at 15c per tonne km. • Users can override with manual entry of haulage costs of each material and vehicle type • Note that rural areas may have higher haulage costs so costs may be on a structured basis, i.e. by region, by vehicle type, by material?
Maintenance	• There is another project that is being run by TMR to review the useful life of pavements. Could the outputs of that project be used for consideration in the maintenance assumptions for the tool? (LD)	• Potentially yes. We'd need to understand the outputs of the TMR useful pavement life review
Maintenance triggers (IRI values)	• Asset management will best answer this. It is also dependent on road types / traffic volumes (PP)	• Maintenance types and frequency should be entered by the user. • We examined whether we could set the model up with maintenance triggers based on IRI values but it was problematic. • Need a separate asset management tool to obtain accurate pavement deterioration and maintenance programs. i.e. beyond the scope and capabilities of this tool. •
IRI Maximum	• Use the IRI maximum values defined in each materials specifications – this would be a very reasonable assumption. For example, foamed bitumen is 1.93m/km (max).	• User entry (see above)
Maintenance costs	• Maintenance would give some guidance on typical costs for each maintenance activity.	• Currently the tables allow for the entry of layer replacement on a lane km basis. Decide which layers and how much of each layer to remove. And how much to replace.

Topic	Stakeholder comments SS= Stephen Hulme PB=Peter Bryant PP= Philip Pearson LD= Louise Dutton	Response
	• The design would need to assume how much maintenance would be required – for example, 12% total area will require crack filling.	• Model will introduce more granular maintenance types (including repair/crack filling) and frequency options for user entry
End of life and Rehabilitation	• End of design life rehab options can be listed – but that will depend on the original pavement structure and material selection.	• Need to assume users of the model have an understanding and appreciation of this. • Considering EoL residual asset values and salvage values with respect to what can feasible be done with pavement at its EoL.
Recyclability	• Some materials are recyclable – but that will depend on the original pavement structure and material selection.	• Users will be able to specify if material goes stays in the road, can be recycled at EoL, or goes to landfill.
Landfill	• <Note comments>	• Assume all (in-scope) road materials are inert, noting that earthworks and landscaping can produce organic waste but out of scope. • MRWA advised that they consider rubber 'practically' inert
Gaming of the Tool	• Rules need to be set to prevent the tool from being used to game optioneering decisions.	• Default values will be present in the model to provide a consistent and verified assessment basis. There also needs to be reasonable assumptions with regards to the performance of the material. • Any new values should have justification. Internal controls would be needed to ensure this happens. • Louis Bettini (MRWA) advised that ISCA assessments required an evidence base to justify any deviations from default input values.
General model capability and design	• Ability of the tool to "talk" to other TMR software to avoid duplication of data entry. Ralph Loesche (RL) mentioned 3PCM and Expert Estimation Toolbox (LD). • Avoid creating isolated data sets, i.e. make data interconnected; tool should use data that has already been generated, and should also feedback data into exiting data; all data should be synchronised, ideally automatically; a lot of the input data appears to be captured somewhere else already, e.g. Expert estimation toolbox (RL)	• Tool will be designed to use existing datasets. • Integration with other TMR tools outside of current scope. • Automating data entry is outside current project scope – could be considered as potential model enhancements • Note: there is complexity in building a single model to accommodate both TMR and Main Roads' existing datasets – Jon Griffin suggested using Austroads data definitions and categorisations. A consistent basis will be used where possible and where valuable.
	• Potential of the tool to "record and collate" analysis data. TMR is currently working on a project to calculate the GHG footprint of a single year of QTRIP construction and operations. This project is looking at taking material quantities from 3PCM and e-Tender systems. Could the pavement sustainability assessment tool be used to provide the GHG for the pavement (and in future other components of the projects) so that this doesn't have to be duplicated. There could also be some analytical capability across the program. (LD)	• Tool should be able to provide a similar capability for pavements. Further consideration needed.
	• A number of the other LCA's reference data comes from the Australian Life-Cycle Inventory Database Initiative. Has ARRB considered whether we provide the data from P106 to this organisation for integration in their data enabling it to be utilised across industry? (LD)	• To be considered – Not part of project scope, but worthwhile consideration. • Louis Bettini from MRWA can help facilitate amongst the ISCA members.
	• Review of how sensitive the GHG calculations are to State-specific factors? If the difference between WA data, QLD data and National data is immaterial then there is little point to developing and maintaining different datasets. (LD)	• As discussed with the joint WARRIP NACOE PWG – there will be state and regional similarities for some datasets, there will be differences elsewhere (e.g. embodied energy in electricity and energy costs). The two reference datasets don't have to greatly different, but having two does allow for any significant differences to be captured. WARRIP program has emphasised a strong preference for using WA-specific data wherever possible.
Usability of the model (TMR planning group)	• Pavement design is not normally considered at the project planning stage. Projects would just assume the use of the cheapest available product.	• Pavement sustainability tool will allow for beyond business as usual assessments of options.

Topic	Stakeholder comments SS= Stephen Hulme PB=Peter Bryant PP= Philip Pearson LD= Louise Dutton	Response
	• Regional officers don’t have spare time for sustainability assessments. Time to use tool may be restricted depending on project, tool will not be used if time is tight • Sustainability is not at the forefront on regional project managers/decision makers – mostly decisions come down to costs • Concerns that if the tool is used it may establish a higher expectation on sustainability and that projects may end up not going ahead. • Planning group uses conservative modelling data.	• Usability in the planning stage may require an allowance for selection between pre-filled pavement designs (e.g. standard base case asphalt or seal vs innovative approaches) – can use P106 designs • By pre-populating the tool with default/reference data, user input is minimised and assessment can be done very quickly. There is no obligation to report on assessment results – but the tool can be used to improve decision making, i.e. it will not override regional/project managers’ decision-making authority.

APPENDIX C INFRASTRUCTURE (ROAD) LIFECYCLE ASSESSMENT TOOLS

LCA tool	General description	Materials scope	Lifecycle scope	Limitations	Benefits
Off the shelf generic LCA products					
SimaPro [1][2] https://simapro.com/	One of the world's leading lifecycle assessment (LCA) software package for 25 years Subscription costs: • 1st User- 22130 AUD unlimited time and 10590 AUD/year • 2nd User- 16000 AUD for unlimited • Total for 10 expert user licences with 3 years' service contract 178,228 AUD	Generic supply chain scope (multi industry) Built-in inventory of many products and processes from a collection of lifecycle inventory databases covering a variety of industries and applications. The inputs (raw material, energy, etc.) and outputs (waste, emissions, etc.) for some common road construction processes such as concrete material production, asphaltic material production, rock crushing, stone quarrying, and transportation are readily available. Can be used for different applications including: • Water footprint • Carbon footprint • Eco and product design • Determination of key performance indicators • Environmental product declarations	Extraction of raw materials to manufacturing, distribution, use, and disposal.	International resource – not tailored for Australian materials, processes. Not specifically tailored for road construction and maintenance. Some recycled material inputs specific to roads are not included (e.g. RAP and RAS) Software only compatible with Windows. Requires 5 GB of hard drive space for every device running SimaPro on a server.	Widely accepted Developed modelling and visualisation of results Simple to use Entire team can work by using a single database at the same time from different locations all around you. Transparent results that allow for tracking of every lifecycle step

LCA tool	General description	Materials scope	Lifecycle scope	Limitations	Benefits
GaBI [3][4] http://www.gabi-software.com/australia/index/	One of the world's leading Lifecycle assessment (LCA) software for modelling and reporting with intuitive data collection and result analytics Gabi full subscription cost for consultancy firms: Subscription costs: • 1st User- 7700 AUD/yr plus additional cost 2500 AUD/yr for construction material database • Every 2nd User- 3800 AUD/yr plus additional 1250 AUD/yr • It would be around 80,900 AUD/yr for 15 users	Generic supply chain scope (multi industry) Any product, everything from a mobile phone to a match-stick to an airport. Supported by US and European lifecycle inventory databases. Can be used for different applications including: • Carbon and water footprint, including GHG emissions • Eco-design • EPD and PEF • Resource & energy efficiency Ability to develop products that feature small environmental footprints that include reduced water waste, consumption, and GHG emissions.	Ability to model every single element of the product within a system to get a comprehensive lifecycle perspective which can help identify opportunities reduce resource, energy and material usage Outputs include costs, energy, and environmental impact of sourcing and refining every raw material or processed component of a manufactured item.	International resource – not tailored for Australian materials, processes. Not specifically tailored for road construction and maintenance. GaBi lifecycle assessment software's tools, including iReport, often need to be downloaded and updated independently of the main program. The software is somewhat clunky and has a steep learning curve, appearing to still be on their original codebase, which is more than a decade old. Much of the background documentation for the included datasets is empty and lacks transparency, requiring reliance on their support staff.	25 years of experience Widely accepted, Over 10,000 users Easily accessible. Content database maintained with updated costs, energy and environmental impact details Content database saves users time on sourcing each material that you used for processing and manufacturing of items and inputting environmental, energy data.
eToolLCD https://etoolglobal.com/	Australian developed lifecycle tool, mostly used in the buildings and construction sector Software uses data from the Australian National Life-Cycle Inventory (AusLCI) database and the Australasian LCI database. The eToolLCD ratings are based on the impact savings of the final design compared to an applicable benchmark (eTool Global n.d.). Used on the NorthLink WA Stage 1 project. Subscription costs: • Consultant USD 50 /month • Enterprise USD 350/month (Floating license) • It would cost around 9000 USD/yr for 15 users	Generic and flexible for all types of projects	Reporting outputs: CO_2e, Cost, Energy, Water, Land Use, Ozone Depletion, Human Toxicity, etc.	Not road/pavement focussed Mainly focused on infrastructure projects, used for only 214 Australian based projects up to date None of the project is focused on road construction, particularly recycled materials in pavement design	Affordable subscription cost (9000 AUD/Yr for 15 users) Supportive to Australian standards and databases

LCA tool	General description	Materials scope	Lifecycle scope	Limitations	Benefits
Tailored transport infrastructure/road infrastructure LCA products					
IS material's calculator v 1.2 Infrastructure Sustainability Council of Australia (ISCA)	Support tool for the IS rating scheme (v 1.2) which evaluates environmental impacts on projects. Based on the best available data from the Australian national Life-Cycle Inventory database (AusLCI) and its shadow database, complemented with data from Worldsteel for steel products	Reference database covers a wide range of typical construction materials	Manufacture (Cradle to gate) & haulage 1 year of analysis	Excludes use, maintenance and end of life phases. Predefined pavement options – limited flexibility to incorporate other pavement design and construction options. Reuse and recycled materials are not included in the material database. No CBA	Has reference tables including material densities. The transport component from the manufacturer's gate can vary significantly between project/assets, so the ISCA Material Calculator includes options to customise the transport component for each material or product. It may be used to calculate transport emissions where tonnage, distance and vehicle type are known.
IS material's calculator v 2.0 [5]	Support tool for the IS rating scheme 2.0. Requires the determination of a base case and alternative case. Allow entry of EPD registration number for materials and so emissions factors can be identified. IS v 2.0 requires calculation of enviro-points to qualify for the credit.	Updated from v 1.2. to include some crumbed rubber factors. Inclusion of Warm mix asphalt, geopolymer concrete and electrical cables	As per v 1.2. + maintenance, use (operations) and disposal/end of life • Extraction and treatment of raw materials • Product manufacturing • Transport and distribution • Construction processes • Use / Operation of an asset End of life is not included in the Materials Calculator	Only for manufacture and construction and excludes use. Does not have a cost benefit analysis comparing the base case to alternative case built into the tool i.e. does not allow for simultaneous cost evaluations. Inability to enter in local, or state specific emissions factors. Two calculators (ISv1.2 and ISv2.0) have different methodologies for the IS EnviroPoints and ISv1.2and ISv1.2 IS EnviroPoints cannot be compared.	As per 1.2 – reference tables updated.
Carbon Estimation Reporting Tool (CERT) – TfNSW	Estimates a project's GHG emissions profile from detailed design stage through to construction and operation. Sources of information include: • AusLCI lifecycle inventory database • Australian national greenhouse accounts (2016) • Transport Authorities Greenhouse Gas Workbooks (TAGG) • Environmental product declarations.	Pavement materials limited to coarse aggregates, Recycled coarse aggregates ballast Sand Manufactured sand Recycled crushed glass.	• Manufacture • Construction • Maintenance • Transport • Use (equipment) 50 year analysis	Lacks flexibility – Uses pre-defined drop-down menus for pavements limited to coarse aggregates, recycled coarse aggregates, ballast, sand, manufactured sand and recycled crushed glass – difficult to differentiate pavement designs.	Encourages the investigation and implementation of GHG reduction (mitigation) measures. Uses Australian source data Includes operational energy and inputs for road service equipment. May be useful to calculate and/or calibrate/check entry values.

LCA tool	General description	Materials scope	Lifecycle scope	Limitations	Benefits
Carbon Gauge Tool (TAGG) – for pavements (2014)	Supported by the Transport Authorities Greenhouse Gas Workbook (TAGG 2013a) Calculator for the calculation of GHGs on road projects.	Pavement materials; • Concrete • Asphalt • Cement • Aggregate • Steel • Hot mix asphalt processing energy Bitumen • Sand • Water • Lime	• Manufacture • Construction • Maintenance • Transport • Use (equipment) Exclude vehicle usage and end of life (disposal) 50 year assessment period	Excludes vehicle usage and end of life phases - limiting circular economy analysis Lacks flexibility – relies on predefined pavement types and materials. Limited ability to assess innovative designs beyond No use phase for on-road vehicle use	Developed and used in Australia and NZ (include MRWA, TfNSW, VicRoads, Tas DSG, SA, NZTA) Allows for the entry of pavement designs Includes embodied carbon and haulage emissions in calculations. May be useful to calculate and/or calibrate/check carbon values.
Tailored international LCA products					
Pavement Lifecycle Assessment Tool for Environmental Economic Effects (PaLATE) v 2.0 – US-based tool (Recycled Materials Resource Centre (RMRC) 2013	Pavement lifecycle assessment tool for environmental and economic effects. Provides lifecycle environmental effects and costs related to the road design, initial construction, maintenance, plant use and project cost. Environmental outputs include emissions of carbon dioxide, nitrous oxide, particulate matter-10, sulphur dioxide and carbon monoxide as well as energy consumption and leachate information (University of California 2007). Designed by the Consortium on Green Design and Manufacturing from the University of California-Berkeley	Pavement materials	• Manufacture • Construction • Maintenance • Transport Excludes use and end of life phases 40 year analysis	US-data (imperial units) requires conversion of measures Construction productivities too high – thus construction emissions understated compared to benchmark road construction data in Australia The tool is only applicable for use in US conditions (Valentin et al. 2015).	Useful for calculations and calibration in absence of Australian data and tools – imperial units. Includes CBA
World Bank ROADEO Model and User Manual (World Bank & ASTAE 2010)	World Bank Greenhouse Gas Emission Mitigation Toolkit for Highway Construction and Rehabilitation. A toolkit for the evaluation and reduction of GHG emissions in the road construction industry. References IVL report (Stripple 2001) for construction equipment emission factors.	Highway Construction and Rehabilitation	Manufacture (Cradle to gate), construction & haulage	Developed for developing country context and thus assumptions and factors used in calculations are inadequate in the Australian context.	May be useful in calculating and/or benchmarking construction emissions – subject to productivity factors.
Inventory of Carbon & Energy (ICE) Version 2.0 University of Bath, UK. (Hammond & Jones 2011)	Developed by the Sustainable Energy Research Team (SERT), Department of Mechanical Engineering University of Bath, UK. Provides an inventory of carbon and embodied carbon.	• Aggregates • Aluminium (recycled and virgin) • Asphalt (4-8% binder content) • Bitumen • Plastic (wide range) • Cement	Manufacture (cradle to gate) only	Based on UK database Not a Lifecycle tool International data not always directly comparable in Australia	Includes an inventory of carbon and embodied carbon for a range of materials including road construction materials. Potential source of reference data (where Australian data gaps exist). Other Australian LCA tools reference this database.

LCA tool	General description	Materials scope	Lifecycle scope	Limitations	Benefits
ECORCE v 2.0 (ECO-comparator applied to Road Construction and Maintenance) (2013) [6]	Developed by Ifsttar (French Institute of Science and Technology for Transport, Spatial Planning, Development and Networks) in 2013.	• Pavement materials includes • Aggregates • Binders (cement, Bitumen) • Steel • Chemical Additives	• Manufacture • Construction • Maintenance • Transport	Developed for French context. French language – language barrier.	Raw material extraction to waste disposal. Benchmark comparison in absence of Australian data. The tool is able to assess initial construction and maintenance policies
IVL Swedish Environmental Research Institute – Lifecycle Assessment of Road (Stripple 2001) [7]	Study done in Sweden. Reference text.	Material database starts from extraction of materials to reuse of roads at the end of cycle. • Bitumen • Crushed aggregates • Electrical energy • Heating oil • Fuels	• Manufacture • Construction • Maintenance • Use (equipment) 40 years Extraction of raw materials, the production of construction products, the construction process, the maintenance and operation of the road and finally the disposal/reuse of the road at the end of the lifecycle (end of the analysed time period).	Swedish context. Emissions by pollutant type – not consolidated for all GHGs	Provides emissions factors for different equipment types Provides some reference productivities for different Classes of construction equipment.
SEVE (Système d'Evaluation des Variantes Environnementales)	SEVE is a software developed by USIRF (Union des Syndicats de l'Industrie Routière Française) for the road industry. Although maintenance activities can be considered in the analysis, they are not included when the software is used for tendering purposes (IDRRIM 2013; USIRF n.d.).	Materials categories include: • natural aggregates • excavated materials • RAP • recycled materials. Inputs include: • transport type and distances • fuel type • manufacture temperatures • percentage of each material in the mix • project quantities • water content • project duration • operations within the project (earthworks, different pavement layers etc.).	Quantitative indicators include energy consumption, CO2 emissions, savings in natural resources (natural aggregates, RAP, recycled materials and excavated materials consumed) and tonne-kilometres.	Based on French database	Qualitative indicators comprise water management and biodiversity considerations
Asphalt Pavement Embodied Carbon Tool (asPECT)	The Transport Research Laboratory (TRL) developed a whole-of-life greenhouse gas emissions tool for asphalt used in	The tool focusses on greenhouse gas emissions related to asphalt and its lifecycle rather than road	Enables users to calculate the GHG emissions in CO2-e units for each stage	Does not include non-carbon-dioxide emissions in the analysis as they are assumed	The user-friendly tool allows practitioners to assess the GHG emissions of individual road

LCA tool	General description	Materials scope	Lifecycle scope	Limitations	Benefits
	highways, known as the Asphalt Pavement Embodied Carbon Tool (asPECT).	construction projects as a whole. Furthermore, related to the use of WMA, asPECT provides detailed guidance on the data required for assessment and how to calculate emissions for each component. The program considers the CO2e impacts of building and maintaining a road pavement, from sourcing raw materials and laying mixtures to maintenance through periodic interventions to ultimate deconstruction.	of the lifecycle, including procurement, during and after construction and at periodic stages of the asphalt pavement design life. (TRL 2011). Considers all emissions that contribute to climate change from sources including energy use, combustion processes, chemical reactions, service provision delivery.	to be insignificant in terms of asphalt life, based on research. Limited in regard to asphalt production and is focussed on the asphalt rather than the project as a whole. Based on UK data / circumstances. Not particularly user friendly, i.e.. requires asphalt mix specifications and origin of energy used during asphalt production. Difficult for non-specialist to acquire reliable calculation results or even rough estimates.	constructions based on the whole-of-life asphalt emissions Enables users to see where the largest sum of emission takes place helping them to focus on those features only for accomplishing improvements The detailed level of the environmental database makes it possible to differentiate a lot among the asphalt mixtures, energy origin and equipment used. This means that calculations can very project specific rather than just generating a rough estimate.
National Asphalt Pavement Association's (NAPA's) Greenhouse Gas Calculator (GHGC2)	US NAPA's Greenhouse Gas Calculator (GHGC2) calculates GHG emissions from asphalt manufacturing based on a **gate-to-gate analysis.** The calculator uses emission factors (GHG emitted per unit of energy) set by the Climate Registry.	Asphalt materials Fuels included: natural gas, biofuel, coal, fuel oil, heavy oil, kerosene, landfill gas, propane and recycled oil.	This tool was developed to calculate emissions from asphalt production only and is not a life-cycle-analysis tool. Since fuel consumption is already accounted for within the use inputs, these credits are not accounted for in the emissions calculation.	Not a lifecycle tool Requires knowledge of quantities of different types of fuel used in the production of asphalt and the factors included in the calculation are based on US conditions.	Allows the user to choose from an extensive list of fuels including natural gas, biofuel, coal, fuel oil, heavy oil, kerosene, landfill gas, propane and recycled oil. Emission offset credits are calculated with the use of WMA, RAP and reclaimed asphalt shingles (RAS) (NAPA n.d.). GHGC2 is a relatively simple tool that allows comparison of greenhouse gas emissions from the production of different asphalt mix technologies and the use of different sources of energy. It provides a more accurate estimation of emissions than other generic LCA tools.
Greenhouse Gas Calculator for State Departments of Transportation (GreenDOT)	GreenDOT calculates carbon emissions from the operations, construction, and maintenance activities of US state Departments of Transportation (DOTs). GreenDOT was developed under the National Cooperative Highway Research	The Materials Module calculates emissions embodied in roadways, based on volumes and types of materials used. The module estimates the impact of mitigation strategies including using recycled materials and warm mix asphalt	Embodied emissions are associated with energy used in the extraction, processing, and transportation of materials. Calculates emissions for	Data is specific for US circumstances	Most of the inputs are not easy to collect. However, the tool provides other possibilities to estimate these inputs.

LCA tool	General description	Materials scope	Lifecycle scope	Limitations	Benefits
	Program (NCHRP) by ICF International and Venner Consulting.		geographical areas ranging from a single project to an entire state, and over time periods ranging from one day to several years.		

References:

1. https://www.semtrio.com/en/life-cycle-assessment-software-simapro
2. https://lcasymposium.ict.illinois.edu/files/2018/01/20_Final-Paper_Development-of-an-Environmental-Life-Cycle-Assessment-LCA-Protocol.pdf
3. https://journals.sagepub.com/doi/pdf/10.3141/2646-04
4. https://trimis.ec.europa.eu/project/clean-vehicle-research-lca-life-cycle-analysis-and-policy-measures
5. https://isca.org.au/getmedia/992b247a-3153-42f9-a4ee-7bf83680228a/2018-02-21_ISCA_Materials_Guideline_Version_2-0_Rev_0.pdf.aspx
6. https://www.researchgate.net/publication/273520125_Road_LCA_the_dedicated_ECORCE_tool_and_database
7. https://www.ivl.se/download/18.343dc99d14e8bb0f58b734e/1445515385608/B1210E.pdf

APPENDIX D INPUT DATA DATABASE

Note: the following information was accurate at a point in time and is subject to amendments during the development and refinement of the model.

Information management	
Model version	Date
MVP	

Assessment Basis							Road alignment	
Name	Road type	Location	Lane Width	Lane Length	Number of Lanes	Assessment Period	Rise & fall	Curvature
Text	Code	Name	m	km	number	Years	m/km	degrees/km
Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential	Essential
	Select from drop down menus	Select from drop down menus	3.5	1	1	40	Select from drop down menus	Select from drop down menus

Overall Pavement Name: <to be inserted>		Pavement design				
Pavement layer	Name / Description	Material(s)	Mass(s) of material(s)	Thickness	CBR %	Layer Density
	Text	Text	%	mm	%	kg/m³
	Essential	Essential	Essential	Essential	Essential	Preferred
Wearing course		Select from drop down menus			N/A	Data populated from look-up tables
Intermediate course					N/A	
Basecourse					N/A	
Prime						
Initial seal						
Improved subgrade					N/A	
Subgrade					N/A	
Subbase						
Tack/bond coat						
SAM/ SAMI						
Reseal						

Overall Pavement Name: <to be inserted>		Maintenance		End of life
Pavement layer	Name / Description	Existing layer thickness removal	New layer constructed	Fraction sent to landfill
	Text	mm	mm	%
	Essential	Essential	Essential	Preferred
Wearing course				Default value=0
Intermediate course				
Basecourse				
Prime				
Initial seal				

Improved subgrade				
Subgrade				
Subbase				
Tack/bond coat				
SAM/ SAMI				
Reseal				

Parameter Values - Material Properties													
Input Data	Density	Emissions (Mine to End of Production)	Wearing course	Inter-mediate course	Base-course	Prime	Initial seal	Improved subgrade	Sub-grade	Sub-base	Tack/ bond coat	SAM/ SAMI	Reseal
Unit	kg/m^3	t CO_2-e / tonne	Mass % in Layer										
Material input	Preferred	Preferred	Essential										
Air Voids	0	0											
Asphalt	2300												
Asphalt, 4% bitumen (binder) content (by mass)	2300	0.066											
Asphalt, 5% bitumen content	2300	0.071											
Asphalt, 6% bitumen content	2300	0.076											
Asphalt, 7% bitumen content	2300	0.081											
Asphalt, 8% bitumen content	2300	0.086											
Binder - bitumen	1000	0.63											
Cement - Portland	1860	0.82											
Coarse Aggregate (e.g. crushed rock)	2240	0.0052											
Concrete - reinforced	2300												
Crumb Rubber	1200	0.0024											
Crushed Brick/Glass/Concrete	1920	0.004											
Fine aggregate (e.g. crushed rock)	2240	0.005											
Lime (calcined)		1.09											
Recycled Asphalt Pavement (RAP)	2000	0.009											
Sand	2240	0.0051											
Soil - common	1460	0											
Other (tbc)													

Parameter Values - Vehicles			
Input Data	Truck Type	Articulated Truck emissions	Rigid Truck emissions
Unit	Name	t CO_2-e per 1 tonne moved 1km	t CO_2-e per 1 tonne moved 1km
MRWA Input	Essential	Preferred	Preferred
Value	Rigid / Articulated	0.000072088	0.00021647

Materials Haulage - Design and Process Parameter					
Materials Haulage Transport Mode			Materials Haulage Distance from source		
Materials Haulage Transport Mode	Materials Haulage - Maintenance Transport Mode	Materials Haulage - End of Life Transport Mode	Materials Haulage Distance from source	Materials Haulage - Maintenance Distance from source	Materials Haulage - End of Life Distance from source
Truck type: Select from drop down menu	Truck type: Select from drop down menu	Truck type: Select from drop down menu	km	km	km
Essential	Essential	Essential	Essential	Essential	Essential

Process Parameters						
Lifecycle Phase	Maintenance Intervals		Maintenance			
Input Data	Maintenance requirements years 1 to 40	Maintenance Level (IRI / NAASRA threshold)	Maintenance Cost per cycle	Equipment emissions due to maintenance	Materials Haulage Transport Cost ($/t.km)	Materials Haulage Transport Cost ($/km)
Unit	years	m/km	$/km	t CO_2-e	$/t.km	$/km
MRWA Input	Essential	Essential	Preferred	Preferred	Preferred	Preferred
Value	Input from fuel model (see table below)		To be sourced	To be sourced	To be sourced	To be sourced

Process Parameters						
Lifecycle Phase	Construction		End of Life (Construction and demolition waste)			
Input Data	Costs	Emissions	C&D emissions	C&D levy cost	C&D disposal cost annual growth rate	C&D disposal cost per cycle
Unit	$/km	CO_2-e /km	t CO_2-e	$/tonne	$/year	$/tonne
MRWA Input	Preferred	Preferred	Preferred	Preferred	Preferred	Preferred
Value	To be sourced	To be sourced	To be sourced	To be sourced	To be sourced	To be sourced

Fuel Model - Vehicle Types (straight, flat road alignment)							
Input Data	Gross Combined Vehicle Mass (GCM)	Base Fuel Consumption	K Factor 1	K Factor 2	K Factor 3	K Factor 4	K Factor 5
Unit	tonnes	L/100km	Number	Number	Number	Number	Number
MRWA Input	Not required	Not required	Not required	Not required	Not required	Not required	Not required
Small Car GCM	1.2	6.419556	0.441226	12.43718	0.0000668	0.006151	0.149391
Medium Car GCM	1.4	7.771756	0.429248	14.42872	0.0000578	0.005364	0.122652
Large Car GCM	1.6	9.826507	0.473008	15.01703	0.000047	0.004258	0.08713
Courier Van-Utility GCM	2.15	7.609467	0.284026	19.36752	0.0000691	0.006175	0.110658
4WD Mid-Size Petrol GCM	2.73	10.24522	0.464267	14.11609	0.0000505	0.005148	0.063315
Light Rigid GCM	3.75	8.085994	0.239071	13.9732	0.000116	0.012785	0.099828
Medium Rigid GCM	10.4	12.45859	0.36312	9.564724	0.0000997	0.014856	0.048677
Heavy Rigid GCM	22.5	23.22869	0.243735	14.52463	0.0000995	0.012912	0.019901
Heavy Bus GCM	19	23.33246	0.271022	14.12877	0.0000685	0.011434	0.01995
Artic 4 Axle GCM	31.5	27.24712	0.160111	12.59432	0.000116	0.019467	0.021969
Artic 5 Axle GCM	39	30.44964	0.265547	11.51051	0.000103	0.017613	0.014919

Artic 6 Axle GCM	42.5	33.79927	0.303256	10.38151	0.0000934	0.017999	0.013406
Rigid + 5 Axle Dog GCM	59	38.14329	0.302384	9.066662	0.0000858	0.02207	0.011962
B-Double GCM	62.5	41.48179	0.32033	8.323599	0.0000796	0.022113	0.010988
Twin steer + 5 Axle Dog GCM	64	40.98332	0.321609	8.44159	0.0000801	0.022176	0.011101
A-Double GCM	79	47.75104	0.300993	7.10185	0.0000717	0.024567	0.009609
B Triple GCM	82.5	50.31407	0.30429	6.703995	0.0000689	0.024871	0.009132
A B Combination GCM	99	54.29232	0.287536	6.08939	0.0000664	0.027662	0.008529
A-Triple GCM	115.5	58.66595	0.27658	5.547481	0.0000639	0.029925	0.00794
Double B-Double GCM	119	61.23917	0.280027	5.283165	0.000062	0.029966	0.007613

Fuel Model - Other Data						
Input Data	IRI or NAASRA, years 1-40	AADT, years 1-40	AADT growth	speed	Maintenance requirements years 1 to 40	Emission Conversion Factors (Matrix)
Unit	m/km	veh no./day	%	km/h	yes/no	Numbers
MRWA Input	Essential	Essential	Essential	Essential	Essential	Not required
Value	[Array] or Formula		2.50%		every 16 years	[Matrix]

Fuel Model – Road Categories	
Input Data	Traffic Distribution
Unit	% of HV
Hierarchy	Preferred
ABS - Capital City Area	1.3878
ABS - Other Urban Area	1.6606
ABS - Other Area	6.1527
Urban - 5% HV	5%
Rural - 10% HV	10%
Rural - 15% HV	15%
Remote Rural - 20% HV	20%

Sensitivity Analysis			
Name	Carbon Price (a)	Discount Rate (a)	Emission Reduction Factors Years 1-40 (a)
	$	%	%
	Optional	Optional	Optional
Low	12.22	0.04	N/A
Medium	30.57	0.07	N/A
High	48.91	0.1	N/A
Base	30.57	N/A	[Array]

APPENDIX E IS RATING SYSTEM AND CREDIT DESCRIPTIONS

E.1 IS RATING SYSTEM

The Infrastructure Sustainability Council of Australia (ISCA) rating scheme is an industry compiled sustainability performance assessment tool that evaluates sustainability in planning, design, construction and operations in all infrastructure.

ISCA defines sustainability consistent with global definitions including but not limited to other sustainability rating tools and the UN Sustainable Development Goals (UN SDGs) i.e. “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Sustainable infrastructure is infrastructure that is planned, designed, constructed and operated to optimise environmental, social and economic outcomes over the long term.

The IS rating scheme 1.0 was first released in 2012. Version 2.0 was released on 1 July 2018. Key modifications of the version 2.0 include alignment to UN Sustainable Development Goals on Projects.

Any tool to assist with decision making needs to be compatible with the ISCA rating scheme requirements to enable informed decision making.

It includes the following components:

- The IS Technical Manual
- IS Rating Tool Score Card (IS score card)
- IS Material Calculator
- Various guidelines that support the application of the tool.

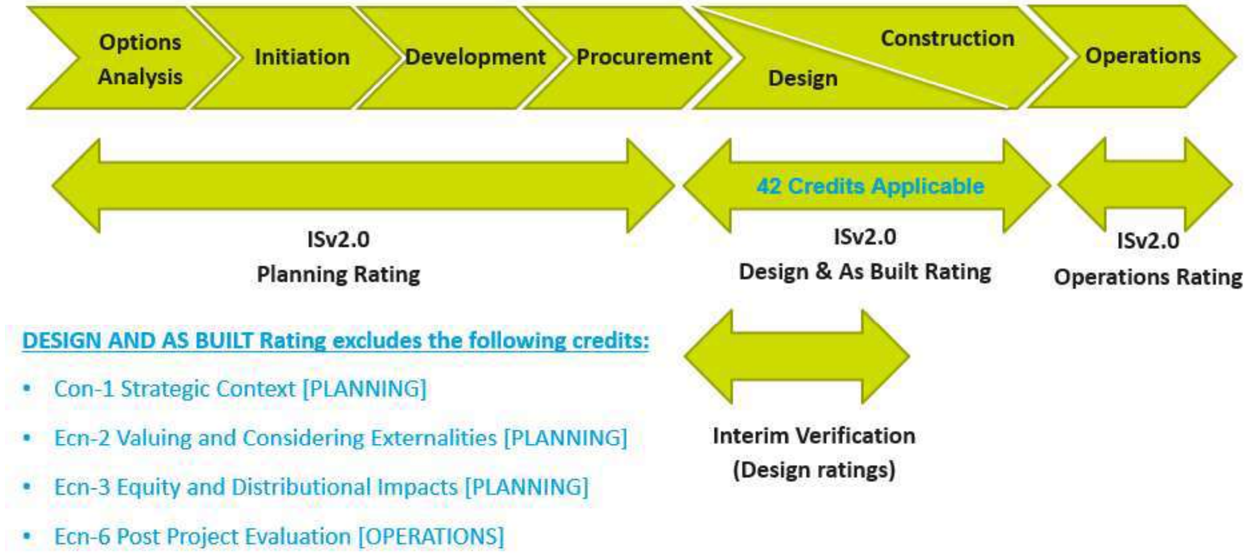
Key changes to the version 2.0 compared to version 1.2 include:

- Better alignment with the UN’s Sustainable Development Goals (SDG) to drive best practice while actively delivering on the SDG’s
- Provision of a comprehensive quadruple bottom line assessment
- Broadening the assessment to include economic and social elements (additional credit requirements)
- New rating award levels (bronze, silver, gold, platinum and diamond)
- Better clarity in terms of mandatory ‘must’ statements and ‘should’ guidelines
- Credits written for each phase of the infrastructure lifecycle to clearly outline the requirements at each phase - Design Phase and ‘As Built’ phase.

E.2 IS RATING PROCESS

Figure E.1 provides information about the scope of the IS version 2.0 assessment rating stages. It is possible to achieve a Design and As Built rating without undertaking a voluntary planning rating.

Figure E.1 Ratings at each stage of the IS 2.0 rating process



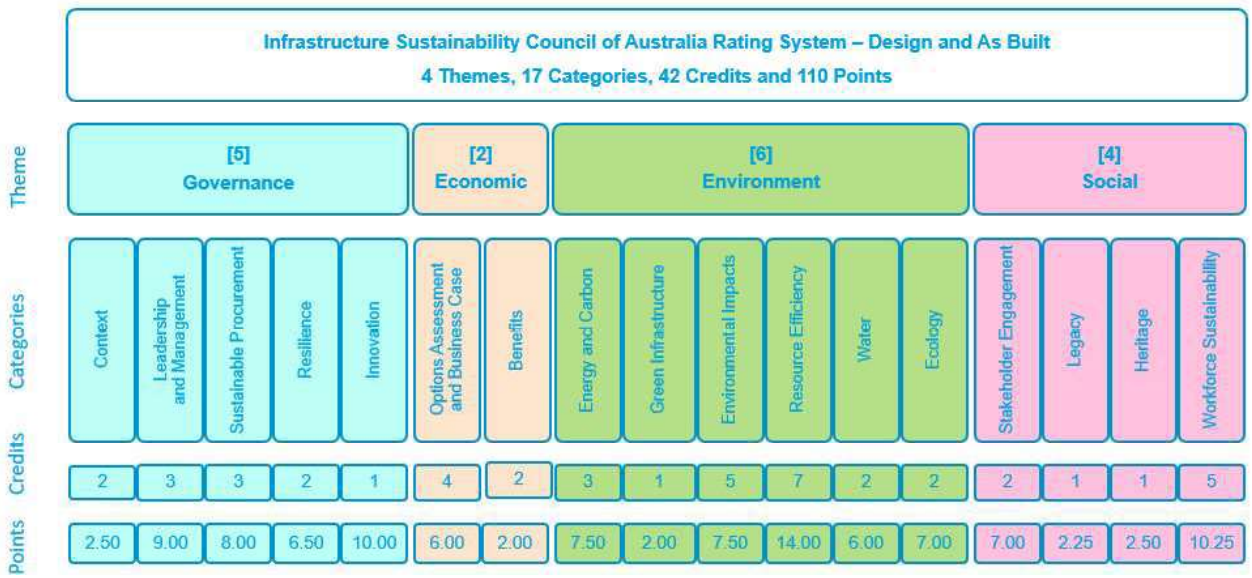
Source: ISCA

E.3 IS RATING THEMES, CATEGORIES, CREDITS AND POINTS

Figure E.2 provides an overview of the themes, categories, credits and points applicable in IS version 2.0. The assessment is out of 100 points and there are an additional 10 points available for demonstrating innovation. Points reflect a default weighting for each points and categories. The weightings for each may be adjusted in accordance with the relative importance in the materials weightings and/or sustainable development goals and early in the design stage. This is part of a workshop undertaken as part of this process in alignment with the Lea-1 'Integrating Sustainability' credit requirements.

There may be difference importance weightings required for Main Roads procurement decision making and compared to the ISCA sustainability rating. The Main Roads procurement decision weighting criteria may include sustainability aspects as a subcategory including CO_2-e.

Figure E.2 IS ratings themes, categories, credits and points



Source: ISCA

The IS rating process require assessments to be conducted with the use of a 'base case' compared to an innovative project alternative case. Within each credit there are 3 levels of achievement that impact how many points are allocated. Some credits allow for points achievement on a sliding scale. The levels transition from compliance towards beyond compliance and excellence. E.g.:

- Level 1 - indicates measurement
- Level 2 - indicates a no net impact achievement
- Level 3 - indicative of restoration and enhancement of the credits.

E.4 POTENTIAL FUTURE ALIGNMENT OF THE SUSTAINABILITY ASSESSMENT TOOL WITH THE IS RATING SYSTEM

Table E.1 identifies the ISv2.0 ratings and the potential future alignment of the sustainability assessment tool.

Table E.1: IS 2.0 rating credits and possible future alignment with the sustainability assessment tool

Governance	Context	Con-1	Strategic Context	
		Con-2	Urban and Landscape Design Context	
	Leadership and Management	Lea-1	Integrating Sustainability	
		Lea–2	Risks and Opportunities	
		Lea-3	Knowledge Sharing	
	Sustainable Procurement	Spr-1	Risk and Opportunity Assessment and Procurement Strategy	
		Spr-2	Supplier Assessment and selection	
		Spr-3	Contract and Supplier Management	
	Resilience	Res-1	Resilience strategy	X
		Res-2	Climate and Natural Hazard Risks	X
	Innovation	Inn-1	Innovation	
Economic	Options Assessment and Business Case	Ecn-1	Options Assessment	X
		Ecn-2	Valuing and Considering Externalities	N/A
		Ecn-3	Equity and Distributional Impacts	N/A
		Ecn-4	Economic and Financial Sustainability	X
	Benefits	Ecn-5	Benefits Mapping	
		Ecn-6	Post Project Evaluation	
Environment	Energy and Carbon	Ene-1	Energy Efficiency	X
		Ene-2	Renewable Energy	X
		Ene-3	Offsetting	X
	Green Infrastructure	Gre-1	Green Infrastructure	
	Environmental Impacts	Env-1	Receiving Water Quality	
		Env-2	Noise	
		Env-3	Vibration	
		Env-4	Air Quality	
		Env-5	Light Pollution	
	Resource Efficiency	Rso-1	Resource Strategy Development	?
		Rso-2	Contamination Remediation Material	?
		Rso-3	Management of Acid Sulphate Soils	?
		Rso-4	Resource Recovery	

		Rso-5	Adaptability	
		Rso-6	Material Lifecycle Impact Measure and Management	?
		Rso-7	Sustainability Labelled Products and Supply Chain	
	Water	Wat-1	Water Use	
		Wat-2	Appropriate use of Water Sources	
	Ecology	Eco-1	Ecological Assessment and Risk Management	
		Eco-2	Ecological Monitoring	
Social	Stakeholder Engagement	Sta-1	Stakeholder Engagement and Strategy Development	
		Sta-2	Stakeholder Engagement and Strategy Implementation	
	Legacy	Leg-1	Leaving a Lasting Legacy	
	Heritage	Her-1	Heritage Assessment and Monitoring	
	Work Force Sustainability	Wfs-1	Strategic Workforce Planning	
		Wfs-2	Jobs ad Skills	
		Wfs-3	Workforce Culture and Well Being	
		Wfs-4	Diversion and Inclusion	
		Wfs-5	Sustainable Site Facilities	

Source: ISCA and ARRB

E.5 ISCA APPLICABLE THEMES AND CREDITS – MATERIALS AND CO_2-E

Applicable credits are subject to the technology being assessed and context. Those applicable to pavement technologies for this tool scoping include, but are not limited to:

- Leadership and Management: Lea-1 Integrating Sustainability
- Leadership and Management: Lea-2 Risks and Opportunities
- Energy and Carbon: Ene-1 Energy Efficiency
- Energy and Carbon: Ene-2 Renewable Energy
- Energy and Carbon: Ene-3 Offsetting
- Economics: Ecn-1 Options Assessments
- Economics: Ecn-4 Economic Viability and Financial Affordability
- Resilience: Res-1 Resilience Strategy
- Resilience: Res-2 Climate and Natural Hazard Risks.

The materials assessments associated with water use efficiency and water quality may also be applicable in the future under the Water category. It may be beneficial also to identify key recycled materials stockpiles and water supplies in the future to help industry inform both procurement strategies and considering different quality, quality and cost of various materials. Future model enhancements or assessments would require a detailed review of other credit requirements.

Similarly, the Ecology credits associated with tree clearing may also be an option to be considered.

APPENDIX F USING COST BENEFIT ANALYSIS TO SUPPORT DECISION MAKING

The following describes how the core model scope could be used for procurement or technology selection purposes:

- A Cost Benefit Analysis (CBA) uses a Discounted Cash Flow (DCF)
- A DCF is used to evaluate projects that have benefits and costs that accrue over many years e.g. a project lifecycle
- The key metric used in the IS process economics credits is the Net Present Value (NPV)
- The NPV method is used in decision making to:
  - Select or reject a project - base case (B) vs. innovative pavement case (A)
  - Select a project from several alternatives (multiple innovative pavement designs)
  - Rank projects in the order of priority for implementation within a budget constraint
  - Inform design decisions as part of techno-economic evaluation [performance target and cost targets].
- The tool is a private benefit-cost analysis decision making tool (government OR industry – a single stakeholder).

Table F.1 describes the discounted cash flow analysis concepts that apply.

Table F.1: Discounted cash flow analysis concepts

Discounted Cash Flow (DCF)	Decision making technique that evaluates multiple years and decision investment options. Uses a cashflow (cost and benefit streams) and discount factors.
Present Value (PV)	The value of the sum of future financial flows in today's dollars. Provides a common basis for comparison of options.
Net Present Value (NPV)	Method to compare investment options. NPV = PV (A) – PV (B) Used to compare or rank investment decisions e.g. Base Case (B) vs. Alternative Innovative Pavement (A).
Discount Factor (DF)	Tells you the amount (multiplier) to convert it to present value (today's dollars). Considers the time value of money (opportunity forgone, risk, and inflation in factors). TMR: 4%, 7% and 10% Discount rate applicable. Typically uses annuity tables or calculations as a multiplier.
Cost Benefit Analysis (CBA)	A method of appraising and evaluating investment alternatives using DCF.

An externality happens when there is no market connection between those taking an action - which has consequences for the material welfare and those affected by the action (public and environment). An example is dumping chemicals in a river that affects people downstream at no cost to the polluter. Incorporating an externality into decision making of the polluter is incorporation of the 'polluter pays' principle into decision making.

Environmental economics is a stream of economics where the costs/benefits of externalities are given a 'monetary value'. Environmental externalities can therefore be incorporated into cost-benefit analysis methods for investment decision making purposes.

There are different valuation techniques for putting a value on externalities. An example is putting a price on greenhouse gases or a carbon price ($ / tonne CO_2-e). Different evaluation approaches include damage cost, abatement cost or traded carbon price.

By incorporating a price of carbon and including it into Main Roads' costs, externality costs can be incorporated into Main Roads' investment decision making processes.

Three major steps of a cash flow analysis include:

1. Identification of the costs and benefits (including optional externalities – a switch/scenario analysis)
2. Valuation of the costs and benefits
3. Comparison of the costs and benefits
4. Sensitivity Analysis (e.g. carbon price, discount factors, technical parameters etc).

Table F.2 outlines NPV decision making rules.

Table F.2: NVP decision making rules for different decision types

For accept or reject decisions	If NPV ≥ 0, then accept the alternatives. If NPV ≤ 0, then reject the alternatives.	If TMR deciding to use the traditional 'base case' technology or the innovative technology and considering all lifecycle cost and benefits.
When choosing or ranking alternatives	If NPV (A) > NPV (B), choose A. If NPV (B) > NPV (A), choose B.	Choosing between multiple innovative designs and considering all lifecycle costs in a D&C contract and compared to a 'base case'. Ranking of procurement tenders or alternative technology options.
Techno-economic evaluation for Design Options (technical and economic criteria)	If NPV (A) > NPV (B), choose A. If NPV (B) > NPV (A), choose B.	Evaluating lifecycle trade-offs or optimising designs e.g. pavement thickness or % recycled materials or combination etc. Lowest cost, highest GHG reductions or multiple indicators.

Source: ARRB