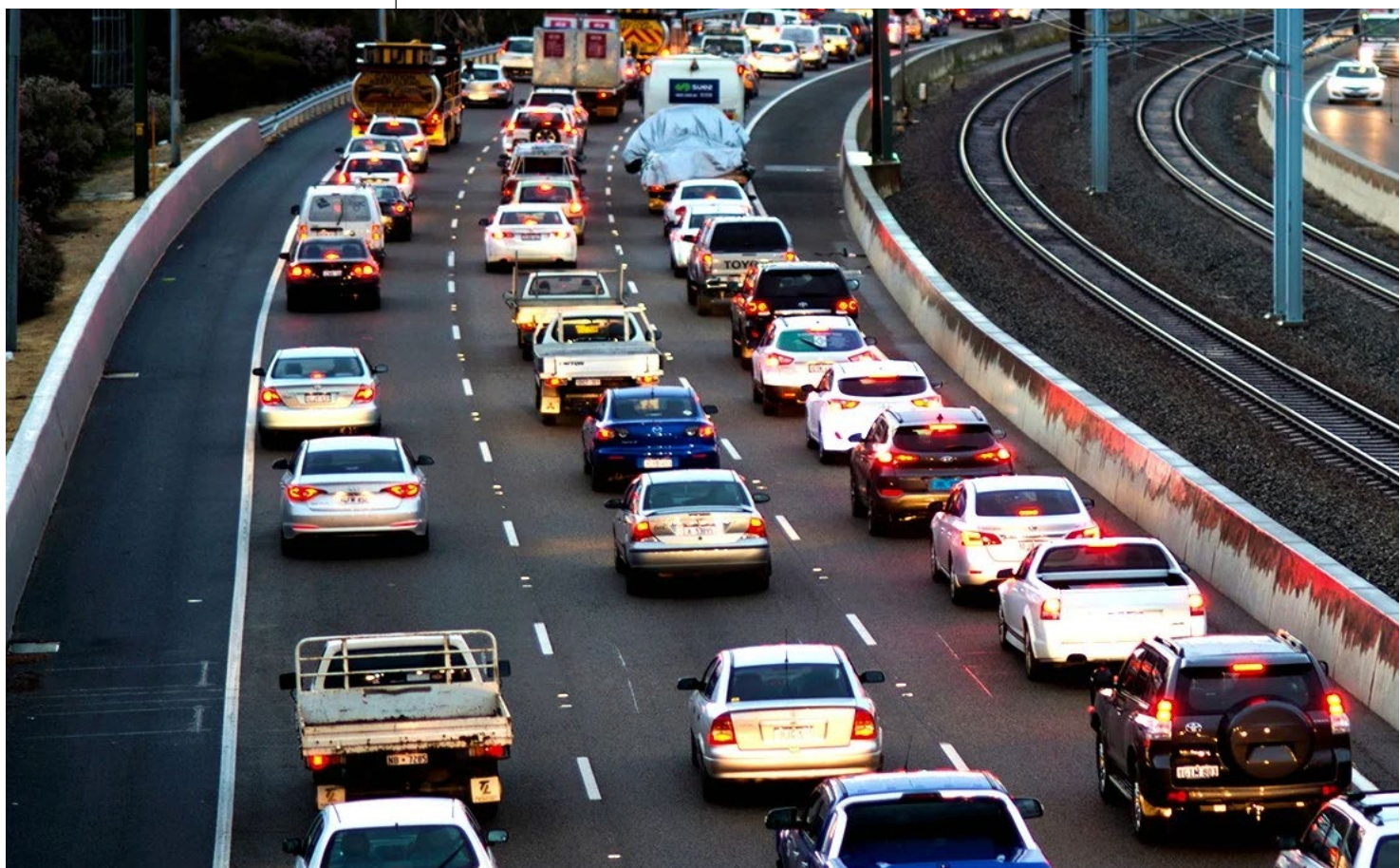


Technical Note: Carbon Valuation in Economic Appraisal of Transport Capital Investment Projects

October 2025



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1. Introduction

1.1. Background

This technical note provides guidance on how to incorporate the value of carbon emissions in transport Cost-Benefit Analysis (CBA). It builds on the principles and methodologies outlined in the *Transport for NSW Cost-Benefit Analysis Guide* ([the CBA Guide](#)) and the accompanying *Transport for NSW Economic Parameter Values* ([the EPV](#)).

The guidance supports the consistent valuation of embodied carbon, operational carbon, and enabled/user carbon emissions in CBAs for transport projects. It applies to:

- Any capital project or program with an estimated total cost of \$100m or above
- Any other projects (capital, recurrent, digital, regulatory change) where the inclusion of carbon values is likely to materially impact the results or investment decision making¹.

Economic appraisal plays a critical role in supporting decarbonisation outcomes by enabling the early identification and valuation of carbon impacts in decision-making. By incorporating user, embodied and operational carbon emissions into cost-benefit analysis, decision-makers can assess trade-offs between options and identify lower-carbon solutions at the stage when influence is greatest. As required under the NSW Government Guide to Cost-Benefit Analysis, carbon emissions should be quantified and monetised in business cases to ensure that carbon reduction is meaningfully considered alongside other social, environmental, and economic impacts. This supports alignment with the Decarbonising Infrastructure Delivery Policy and helps drive more sustainable, whole-of-life infrastructure investments.

This note is intended to complement existing policies and guidance issued by NSW Government agencies, including:

- Decarbonising Infrastructure Delivery Policy (Infrastructure NSW, 2024a)
- Embodied Carbon Measurement for Infrastructure (Infrastructure NSW, 2024b)
- Carbon Emissions in the Investment Framework (NSW Treasury, 2024)
- Guide to Assessing Greenhouse Gas Emissions (Infrastructure Australia, 2024a)

For advice on carbon reporting outside the scope of CBA, project teams are encouraged to contact the **Environment and Sustainability branch** within Transport for NSW.

1.2. Recommendations at a glance

The following carbon valuations are recommended in cost benefit analysis of transport projects:

- **User/Enabled Carbon:** Projects should quantify, monetise and include the user carbon (B8) emitted over the project appraisal period.
- **Operational Carbon:** If data availability permits, other Operational Carbon modules should be quantified and included as well (B1-B7). Project teams should consider the appropriateness of including these values in the core analysis or as a sensitivity test.
- **Upfront Embodied Carbon:** business cases with an Estimated Total Cost (ETC) of \$100 million or more, regardless of funding source, should include the value of upfront embodied carbon (A1-A5) in the project CBA. The upfront carbon emissions are included in the CBA as a disbenefit and should be included in the numerator or the Benefit Cost Ratio (BCR) equation.

¹ It is recommended to consult the Sustainability Section within E&S Branch (SPER Division), who may be able to provide strategic guidance on the likely magnitude of carbon impact for the project under consideration.

If the base case option is to refurbish or carry out other potentially carbon intensive activities in order to preserve / prolong the useful life of existing assets; these are typically considered In-Use Carbon emissions and reported accordingly within a transport CBA report.

Use of Carbon Values: The value of carbon emissions is forecast to change each year until 2050, the end of forecasting period of carbon values, to align with the Net Zero emissions target. Therefore, when evaluating carbon emissions, it is essential to apply the corresponding economic value of carbon for the specific years during which these emissions occur. This can be done using the adjustment factors provided in **Table 2**. For reference, Infrastructure Australia (2024a) provides national carbon values, which are also adopted by ATAP. NSW Treasury (2024) provides state-specific carbon values for New South Wales. For projects seeking a mix of federal and state funding, two core analyses should be undertaken – one using federal values and one using NSW values. For projects funded solely by the state, a single core analysis using NSW carbon values is sufficient. These values are detailed in **Table 3-1 and Table 3-2**.

This guide provides a technical overview and user guide, intended for users with a presumed detailed understanding of CBA modelling and transport economics.

Project teams should consult with TfNSW Economic Advisory for advice on applying the methodologies presented in this technical note. The Economic Advisory team can be contacted by emailing EconomicAdvisory@transport.nsw.gov.au.

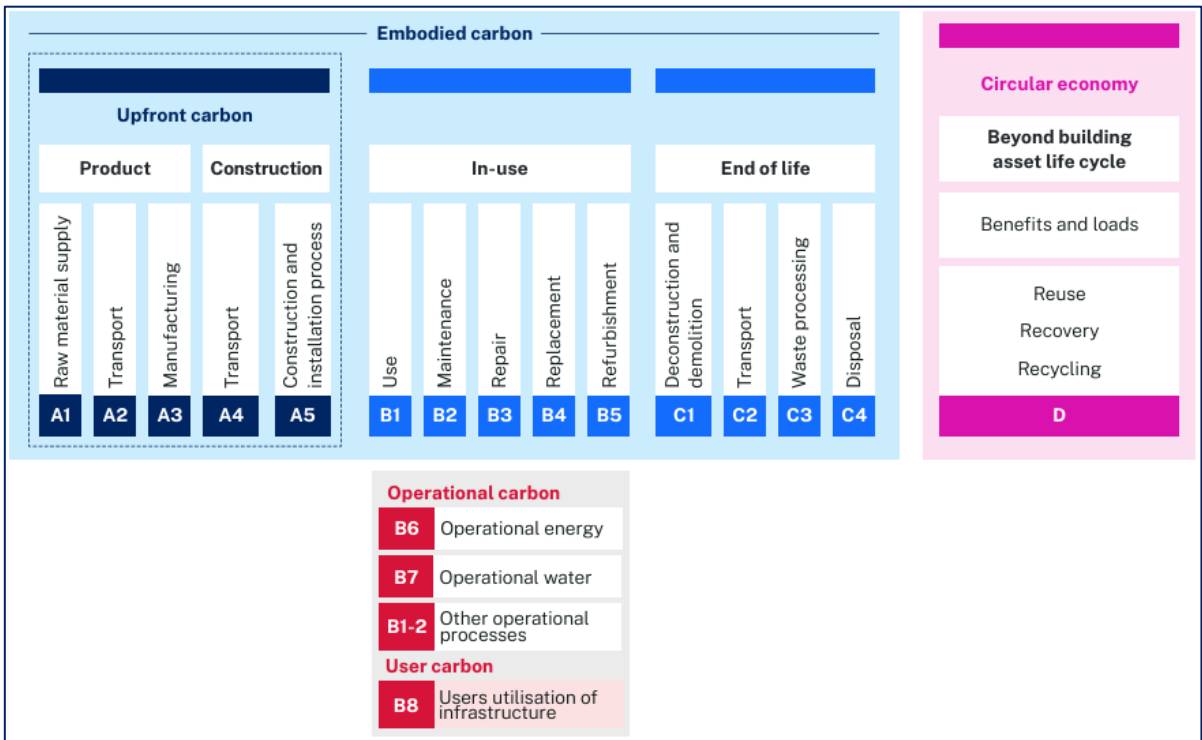
Project teams should consult with TfNSW Environment & Sustainability Branch for advice and feedback on carbon measurement and reporting approaches.

2. Stages of carbon emissions in a project

The carbon emission lifecycle is broadly defined and accepted to span from modules A to D (European Committee for Standardization (CEN), 2011), as illustrated in **Figure 1**.

For the purposes of this technical guidance, the focus is on “Upfront Carbon” (modules A1-A5) and “In Use” carbon (modules B1-B8), which represent significant phases in the carbon emissions lifecycle. Upfront carbon encompasses the greenhouse gas emissions associated with the initial stages of a transport asset’s life cycle, including raw material extraction, transportation, manufacturing, and construction. In-use carbon pertains to the emissions generated during the operational phase of the asset, specifically emissions generated by both the upkeep and use of the asset.

Figure 1: Whole of life carbon emissions modules



Source: Infrastructure NSW – Embodied Carbon Measurement for Infrastructure – Technical Guidance (April 2024)

2.1. Upfront embodied carbon (modules A1 - A5)

The built environment is responsible for 39% of carbon emissions worldwide, with approximately 28% from operational emissions and 11% attributed to construction materials and processes (World Green Building Council, 2019). In Australia, this proportion is even higher, with around 16% of all built environment emissions stemming from the products and materials used in construction (Greenstar, 2022).

Upfront carbon refers to the greenhouse gas emissions associated with the initial stages of an infrastructure asset’s life cycle, specifically covering modules A1 to A5 in the carbon emissions life cycle (Figure 1). These stages are defined as follows:

Product Stage (A1 – A3)

- **A1 - Raw Material Supply:** This includes the extraction and processing of raw materials and fuels required for the operation and construction of an infrastructure asset (e.g., road, bridge,

tunnel, etc). It accounts for emissions from mining, harvesting, and other forms of resource extraction, as well as the initial processing of these materials.

- **A2 - Transport:** This stage involves the transportation of raw materials from their extraction sites to manufacturing facilities. It includes the emissions from fuel combustion in vehicles used for transporting these materials over various distances.
- **A3 - Manufacturing:** This covers the manufacturing processes of construction products and materials. It includes emissions from energy use, chemical processes, and other industrial activities involved in converting raw materials into usable components.

Construction Stage (A4-A5)

- **A4 - Transport to Construction Site:** This stage accounts for the emissions from transporting the manufactured products and materials from the production facilities to the construction site. Similar to A2, it includes emissions from the vehicles used for this transportation.
- **A5 - Construction-Installation Process:** This includes the emissions associated with the actual construction activities on-site. It covers energy use, machinery emissions, vegetation clearing or land-related impacts related to construction, and other construction-related processes involved in assembling the infrastructure asset.

Upfront carbon is a critical consideration in sustainable construction as it represents the initial carbon footprint before an infrastructure asset becomes operational. Consideration of upfront carbon in business cases can materially impact the options analysis process, Cost Benefit Analysis results and ultimately allocation funding / investment.

2.2. In-use embodied carbon (modules B1 – B5)

In-Use embodied Carbon Emissions are the greenhouse gas emissions associated with the use, maintenance and repair of the asset throughout its life cycle. In the context of the built environment, these emissions are captured within the **B1 to B5** modules of the carbon emissions life cycle. In the context of TfNSW projects, this is generally in the form of routine and periodic maintenance, as well as vehicle emissions during the maintenance of a transport asset.

In-Use Carbon emissions can be substantial, particularly in infrastructure projects like roads and bridges, where ongoing use and maintenance activities contribute significantly to the overall carbon footprint. These emissions are broken down as follows:

- **B1 - Use:** This stage includes emissions resulting from the materials and products used during the operation of the installed asset, such as carbonation of cementitious materials (concrete and other cement-based materials absorb carbon dioxide from the air, which can be accounted for as part of the use phase), and carbon sequestration by trees and other vegetation planted around the asset. This module is distinct from B6, which relates to emissions from energy used to power infrastructure during the operation of the asset, and B8, which relates to the 'utilisation' of the infrastructure asset.
- **B2 - Maintenance:** Emissions from routine and periodic maintenance activities required to keep the infrastructure in good operational condition. This includes activities such as road resurfacing, line painting, replacing worn-out components, maintaining rail tracks, servicing ventilation and signalling systems, and minor repairs.
- **B3 - Repair:** This refers to emissions associated with more significant repairs that restore the asset to its original condition after damage or degradation. This includes emissions associated with conducting inspections and diagnostics to determine repair needs, performing physical

repairs (e.g., patching concrete, sealing leaks, fixing structural elements), transport of materials and personnel, use of machinery and equipment, and embodied carbon in repair materials.

- **B4 - Replacement:** Emissions resulting from replacing parts or components of the infrastructure that have reached the end of their useful life. This can include large-scale replacements like bridge deck or road surface renewal.
- **B5 - Refurbishment:** Emissions from extensive refurbishment activities aimed at extending the useful life of the infrastructure, such as strengthening road/bridge/tunnel/track foundations or rehabilitation works.

2.3. In-Use Operational carbon (modules B1 – B2, B6, B7)

Operational carbon refers to emissions produced when operating an asset to deliver its intended function, and includes:

- **B1-B2 - Other operational processes:** this covers active emissions from systems required to run the asset. In transport, this may include refrigerant leakage from air-conditioning systems, or emissions from oils used in vehicles for non-energy purposes, such as lubricants.
- **B6 - Operational Energy Use:** This stage includes emissions from energy used during day-to-day operation of the asset, such as emissions from the electricity or fuel used for heating, cooling, lighting, signalling and signage and traffic control systems and energy management systems.
- **B7 - Operational Water Use:** This includes emissions from the use of water resources during the operation phase, such as water used in vehicle temperature regulation, dust suppression, water pumps/pumping stations, water treatment plants, and to enable water use in buildings and facilities

2.4. User/Enabled Carbon (B8)

User/Enabled/Users' utilisation Carbon refers to the Greenhouse Gas emissions associated with the utilisation of the infrastructure during the use stage. This generally refers to direct tailpipe emissions from vehicles using a road and includes the impact of commuting to a workplace or similar over the in-use stage of an infrastructure assets life-cycle (RICS Professional Standard, 2023). In the context of transport CBA, this also refers to the Well-to-Tank (WTT) emissions associated directly with the asset usage (e.g. VKT). It should be noted that while WTT emissions may in some instances be considered as 'upstream' emissions, they are directly associated with the users' utilisation.

All business cases are required to consider carbon emissions through asset use throughout the appraisal period. This is a disbenefit if the project option results in an increase in CO₂ equivalent emissions. This could be driven by increased Vehicle Kilometres Travelled (VKT), changes in speeds or levels of congestion, or a change in traffic composition to a higher proportion of heavy vehicles. If there is a net reduction in carbon emissions through use/operation, there will be a benefit in the project case.

2.5. End-of-life Embodied Carbon (C1-C4)

The end-of-life stage accounts for the deconstruction and demolition of the construction project and includes the impacts of transport to waste processing sites and the disposal of the waste. This encourages design teams to consider the environmental impact at the end of the life cycle early in the design process, and the use of recyclable/reusable materials to minimise this stage.

- **C1: De-construction and demolition.**
- **C2: Transport to waste processing facilities.**
- **C3: Waste processing for reuse, recovery and/or recycling.**
- **C4: Waste disposal.**

2.6. Circular Economy (D)

This stage covers the net benefits and loads arising from the reuse of products or the recycling or recovery of energy from waste materials resulting from the construction stage, the use stage and the end-of-life stage. Results including Module D are often referred to as taking a “Cradle-to-Cradle” approach.

3. Parameters for use in CBA

Parameters for use in transport CBA are provided in the TfNSW Economic Parameter Values guideline (TfNSW, 2025) (EPV). An excerpt from the EPV is provided in the below sections based on the required information to calculate carbon emissions in transport CBA. Practitioners should consider the timeliness of values provided in this technical note and make adjustments to the relevant base year if required.

3.1. Carbon values for core and sensitivity analysis

The carbon values to be used in transport CBA are detailed in **Table 3-1**, representing a calculated target-consistent marginal abatement cost per tonne of CO₂ equivalent emissions. These values can be used to calculate all carbon impacts including ‘User/Enabled’, ‘Embodied’ and ‘Operational emissions’. The values in **Table 3-1** apply from 2023-24. For carbon emissions occurring in subsequent years, different values must be used. These future values can be determined by applying the adjustment factors provided in **Table 3-2**.

Table 3-1: Carbon emissions value per tonne (\$ per tonne, June 2025)

Price (\$)	Scenario	Carbon Value (2025) (\$)	Carbon Value (2050) (\$)
NSW Funded Projects			
NSW Carbon Value (Core analysis)*	Core analysis	135.74	365.46
Commonwealth and NSW Jointly Funded Projects			
National Carbon Value - Central Estimate **	Core analysis #1	69.95	399.56
NSW Carbon Value (Core analysis)*	Core analysis #2	135.74	365.46
Sensitivity Tests for All Scenarios			
NSW High Carbon Value (Upper-Bound) *	Sensitivity 1	240.16	730.93
National Carbon Value - Central Estimate **	Sensitivity 2 ²	69.95	399.56
National Carbon Value - (Lower-Bound) **	Sensitivity 3	59.35	304.17

Source: NSW Treasury 2024 Carbon emissions in the Investment Framework. Indexed from September 2023 to June 2025 using Sydney CPI; Infrastructure Australia 2024 valuing emissions for economic analysis guidance note, indexed from June 2023 to June 2025 using Australia CPI.

The adjustment factors presented in **Table 3-2** should be used to adjust the core carbon value for emissions beyond 2025. These factors should be used to estimate the carbon values for sensitivity testing. Practitioners can adjust the current NSW core carbon value (\$135.74) to the appropriate sensitivity test values for the respective years of emission.

² If core analysis is National Carbon Value (central estimate) – then Sensitivity 2 should be the National Carbon Value (upper -bound)

Table 3-2: Annual values for carbon emissions value per tonne

Year	NSW Carbon Value (Core analysis)	Sensitivity Test 1: NSW High Carbon Value (Upper-Bound)	Sensitivity Test 2: National Carbon Value - Central Estimate	Sensitivity Test 3: National Carbon Value - (Lower- Bound)
	\$/t CO ₂ e	\$/t CO ₂ e	\$/t CO ₂ e	\$/t CO ₂ e
2024	135.74	240.16	59.35	46.63
2025	135.74	240.16	69.95	59.35
2026	136.79	241.21	80.55	65.71
2027	138.88	243.29	93.27	73.13
2028	143.05	247.47	110.22	80.55
2029	152.45	256.87	130.36	92.21
2030	171.25	280.89	156.86	113.40
2031	204.66	326.83	181.23	131.42
2032	250.60	386.35	203.49	152.62
2033	296.55	444.82	221.51	168.51
2034	329.96	490.77	235.28	175.93
2035	348.76	523.14	248.00	182.29
2036	358.15	545.06	258.60	195.01
2037	362.33	561.77	269.20	202.43
2038	364.42	576.39	279.80	204.55
2039	365.46	589.96	289.34	218.33
2040	365.46	603.54	298.87	222.57
2041	365.46	616.07	308.41	224.69
2042	365.46	628.60	317.95	227.86
2043	365.46	641.13	327.49	241.64
2044	365.46	654.70	337.03	260.72
2045	365.46	667.23	345.51	282.98
2046	365.46	679.76	355.04	288.28
2047	365.46	692.29	364.58	290.39
2048	365.46	705.87	375.18	292.51
2049	365.46	718.40	384.72	300.99
2050	365.46	730.93	399.56	304.17

Source: NSW Treasury 2024 Carbon emissions in the Investment Framework. Indexed from September 2023 to June 2025 using Sydney CPI; Infrastructure Australia 2024 valuing emissions for economic analysis guidance note, indexed from June 2023 to June 2025 using Australia CPI.

3.2. Carbon values for User/Enabled carbon emissions (B8)

3.2.1. Carbon values for passenger transport

Table 3-3 provides carbon emission values specific to passenger transport, measured both by vehicle kilometre travelled and by passenger kilometre travelled. These values are based on the core analysis carbon price of \$135.74 per tonne of CO₂ equivalent emissions. Adjustments for different years and sensitivity tests can be made using the adjustment factors outlined in **Table 3-2**.

Table 3-3: Carbon values of passenger transport (cents per VKT or PKT) (June 2025 \$)

Transport Mode	Indicative occupancy	FY25
By vehicle kilometre travelled		
Motorcycle (two-wheelers)	1.1	1.21
Car (Passenger car – Small, medium, large, SUV/4WD)	1.6	2.47
Mini bus (Light Commercial Vehicles)	5.0	3.59
Bus (standard and articulated vehicle)	19.1	11.39
Light rail (Electric e.g. Sydney Light Rail)	50.7	0.00
Rail (Electric)	141.4	0.00
Rail (Diesel)	141.4	26.18
Ferry (Diesel, e.g. RiverCat)	94.8	67.63
By passenger kilometres		
Motorcycle (two-wheelers)		1.16
Car (Passenger car – Small, medium, large, SUV/4WD)		1.53
Mini bus (Light Commercial Vehicles)		0.73
Bus (standard and articulated vehicle)		0.61
Light rail (Electric e.g. Sydney Light Rail)		0.00
Rail (Electric)		0.00
Rail (Diesel)		0.44
Ferry (Diesel, e.g. RiverCat)		0.70

Source: Estimated by Economic Advisory based on ATAP PV5 2024 and (Deloitte / NSW Govt, 2024). Values are in June 2025 prices (ABS Series ID A2325846C & A2325806K).

3.2.2. Carbon values for freight transport

The value of carbon emissions for freight transport depends on the type of vehicle, the kilometres travelled, and the payload. **Table 3-4** provides parameters for calculating CO₂ equivalent emission costs based on vehicle kilometres travelled (VKT) or payload distance (e.g., 1000 tonne-kilometres). These values can be interpolated for different years, and sensitivity testing can be conducted using the same adjustment factors provided in **Table 3-2**.

Table 3-4: Carbon values of freight transport (June 2025\$)

	FY25
Cents per vehicle kilometre travelled (Cents/vkt)	
LCV	3.59
HV	8.44
Rigid trucks	6.18
Articulated trucks	9.77
Freight trains*	146.41
Dollars per 1000 tonne km (\$)	
LCV	51.87
HV	6.79
Rigid trucks	29.33
Articulated trucks	6.79
Freight trains	3.15

Source: Estimated by Economic Advisory based on ATAP 2024 PV5 and IA Guideline: Estimating a national emissions value for use in economic appraisal. Values are in June 2025 prices (ABS Series ID A2325806K).

* represents Diesel freight trains as a general category aggregating all subcategories of diesel freight train including short and long container trains and those with and without emission control technologies (EGR and SCR) (CE Delft, 2019)

3.2.3. Well-to-tank (WTT) emission costs for passenger and freight transport

Well-to-tank (WTT) emissions refer to all upstream emissions generated during the extraction, production, processing, and distribution of fuels before they reach a vehicle's fuel tank. These emissions include both greenhouse gases – such as carbon dioxide, methane, and nitrous oxide – and noxious pollutants like nitrogen oxides, sulphur oxides, and particulate matter. The processes contributing to WTT emissions encompass activities like drilling or mining for raw energy sources, refining crude oil into usable fuels, and transporting fuels via pipelines, ships, or trucks to distribution centres and filling stations.

Understanding WTT emissions is crucial for evaluating the full environmental impact of energy use in transportation.

It is, however, important to note that the database for WTT emissions is relatively new and currently has considerable uncertainties (CE Delft, 2019). The complexities involved in tracking and quantifying emissions across diverse and global supply chains contribute to these uncertainties. Factors such as variations in extraction methods, differences in refining efficiencies, and the modes of transportation used for fuel distribution can all significantly impact the accuracy of WTT emission data.

Table 3-5 outlines the WTT emissions for passenger transport, detailing values for both vehicle kilometres travelled and passenger kilometres travelled. **Table 3-5** values should be adjusted to the year that emissions are expected to be made using the factors provided in **Table 3-2**. These impacts should also be incorporated into the sensitivity analysis.

Table 3-5: WTT emission costs by passenger transport mode (cents, 2025)

Externality type	Motorcycle	Car	Minibus	Bus	Light rail	Rail	Ferry
Urban Environment							
WTT emissions and pollutions (VKT)	0.44	0.51	0.65	2.47	99.27	216.14	20.76
WTT emissions and pollutions (Passenger Kilometre Travelled)	0.42	0.32	0.13	0.13	0.16 *	0.16 *	0.22
Rural Environment							
WTT emissions and pollutions (VKT)	0.44	0.51	0.65	2.47		216.14	20.76
WTT emissions and pollutions (Passenger Kilometre Travelled)	0.42	0.32	0.13	0.13		0.16 *	0.16 *

Source: Estimated by Economic Advisory based on ATAP PV5 2024 and (Deloitte / NSW Govt, 2024). Values are in June 2025 prices (ABS Series ID A2325846C and A2325806K).

*Manually adjusted from ATAP recommended values. Note ATAP is currently working on updated values. These will be implemented by TfNSW in due course.

Table 3-6 presents WTT emission costs for freight transport in both urban and rural contexts. The choice of urban or rural parameter values depends on the classification of the project scope (i.e., whether it is classified as an urban or rural project). All values should be adjusted using the adjustment factors provided in **Table 3-2** to reflect the year of emissions.

Table 3-6: WTT emission costs by freight transport (cents, 2025)

Externality type	LCV	HV	Rigid trucks	Articulated trucks	Freight trains
Urban Environment					
WTT emissions and pollutions (VKT)	0.65	2.06	0.91	1.44	50.62
WTT emissions and pollutions (Passenger Kilometre Travelled)	9.49	1.66	4.35	0.99	1.13
Rural Environment					
WTT emissions and pollutions (VKT)	0.65	0.04	0.12	0.40	12.15
WTT emissions and pollutions (Passenger Kilometre Travelled)	9.49	1.66	4.86	1.15	1.13

Source: Estimated by Economic Advisory based on ATAP PV5 2024 and (Deloitte / NSW Govt, 2024). Values are in June 2025 prices (ABS Series ID A2325846C and A2325806K).

4. Calculating carbon impacts in Cost Benefit Analysis

To estimate the impact of carbon in CBA, there are three key inputs required:

1. Amount of carbon emissions (measured in tonnes of carbon dioxide equivalent)
2. Year(s) in which the carbon emissions occur
3. Value of carbon emissions in the year(s) they are expected to occur (included in this guide)

4.1. Calculating upfront carbon impacts (A1-A5)

Upfront carbon emissions should be estimated at the business case stage using an accepted methodology. The preference is to do this based on the specific materials and processes involved in the construction, if available; but it also can be calculated more generally based on the proposed CAPEX of a project by 'a comparison against a fixed benchmark' or 'a comparison against a reference project' Methods recognised by TfNSW to estimate upfront carbon emissions include:

1. TfNSW Carbon Tool – a tool for the measurement and management of carbon emissions during business case, design phases and construction of Transport for NSW projects. This tool is provided to TfNSW project partners to complete. The tool can estimate embodied carbon based on detailed project information including types and quantities of materials, construction methods, energy consumption and project logistics. Depending on input information available, the tool will either produce CO₂ equivalent emissions in bi-annual emission periods or the total CO₂ equivalent emissions as a single value. If only the total emissions are produced, this should be apportioned to emission year based on the CAPEX expenditure profile.
2. Infrastructure NSW Embodied Carbon Databook (ECD), where quantity data is unavailable. The ECD provides default emission factors, carbon intensity benchmarks and calculation assumptions to support carbon measurement in line with the Policy. The ECD should be used in conjunction with the INSW Embodied Carbon Measurement for Infrastructure: Technical Guidance (Measurement Guidance) (Infrastructure NSW, 2024b). This approach is also referred to as the Asset Level Carbon Intensity Benchmark (ALCIB) approach.

Once CO₂ equivalent emissions by emission year are estimated, the economic cost of these emissions can be calculated by applying the corresponding economic value of carbon emissions (**Table 3-1**) and adjusting the value for the year the emissions are produced (**Table 3-2**).

These costs should be estimated for the project option, incremental to a base case. Values should then be included in the economic cash flow forecast to determine the nominal and present value of the incremental impact.

4.2. Calculating in-use embodied carbon (B1-B5)

For the purposes of this technical note and to enhance interpretability within a transport project context, in-use embodied carbon primarily refers to Modules B1 through B5. These emissions are associated with maintenance activities specific to the transport asset that occur after it is opened to traffic / public. The main types of maintenance activities considered are:

- **Routine maintenance** - encompass minor enhancement works in order to improve the life of assets within the routine maintenance space (Department of Transport and Main Roads (QLD), 2017). This could include activities such as sweeping of roads, line painting, cutting grass, minor reshaping of ditches, etc.

- **Major periodic maintenance** – This involves more significant interventions such as resealing, resurfacing, or heavy patching of a road. In a rail context this could be activities like ballast cleaning or ballast renewal. These activities are conducted less frequently but have a higher carbon footprint due to the materials and processes involved.
- **Rehabilitation maintenance** – These activities are more extensive and usually require substantial investment and resources, leading to significantly higher carbon emissions. Rehabilitation may involve major structural repairs or complete the rehabilitation.

It is not mandatory to include these emissions in a Cost-Benefit Analysis (CBA). However, practitioners with access to the relevant data and analytical capabilities are encouraged to develop a project-specific approach to estimate them (Infrastructure NSW, 2024a). Currently, there is no established or standardised methodology for calculating these emissions in the context of transport CBAs.

4.3. Calculating User Carbon (B8)

User carbon emissions can be estimated in a CBA using outputs from transport modelling (e.g., Vehicle Kilometres Travelled (VKT) and traffic composition) and the parameter values provided in this guide. For projects involving road vehicle travel, user carbon occurs directly as tailpipe emissions. An additional measure of carbon emissions related to user VKT are the indirect emissions known as Well-to-tank (WTT) emissions. While these emissions occur upstream of user tailpipe emissions, they are attributable to vehicle use (VKT) rather than the built asset itself and are therefore considered separate from the asset's embodied emissions. For the purposes of CBA reporting these are included in the same category, “In Use, Operational and User Carbon emissions” – this is shown in the example Appraisal Summary Table (AST) in **Table 5-1**.

The carbon values presented in **Table 3-3** to **Table 3-4** are in 2025 dollars. For emissions occurring in years after 2025 and for sensitivity calculations, the adjustment factors in **Table 3-2** should be applied to determine the carbon emission value for the relevant year.

4.4. Sensitivity testing

Once carbon emission quantities have been established for each year throughout the appraisal period, the carbon values used in the core analysis can be adjusted using the sensitivity factors presented in **Table 3-2**. Sensitivity tests should be conducted and reported alongside other required sensitivities in the project CBA report.

5. Reporting Carbon Emissions in CBA

Practitioners should include the impact of carbon emissions in the numerator of the BCR equation (NSW Treasury, 2023). Depending on the project context, this impact may be a benefit or disbenefit. This is a core reporting requirement in transport CBA and should be reported as part of an independent benefit/impact category. Best practice is to report Upfront Carbon emissions and In-use Carbon emissions as two separate line-items.

5.1. Upfront embodied carbon emissions (A1-A5):

- Calculate the embodied carbon emissions for the project case. Items that form part of the project OPEX like maintenance and refurbishment works, etc. in the base case will more suitably fall into the in-use carbon modules.
- Include embodied carbon as an independent benefit / disbenefit in the CBA appraisal summary table.

5.2. In-use embodied carbon emissions (B1-B5):

- If in-use embodied carbon is estimated for the project, this should be reported as a separate line item.
- Similarly with other embodied carbon categories, the incremental impact over the appraisal period should be included in the numerator as a benefit / disbenefit.

5.3. User carbon emissions (B8):

- User carbon emissions should be reported separately to embodied carbon and should be included within the “In-Use, Operational and User Carbon Emissions” category of project benefits. Separately to all other environmental impacts measured through the use of the infrastructure asset over the appraisal period.

By reporting A-modules (upfront embodied carbon), B-modules (In-use, Operational and User Carbon) and other environmental impacts independently within the AST, practitioners can clearly distinguish the different sources of carbon emissions and their respective impacts. This approach ensures that the CBA is reported in alignment with NSW government carbon reporting requirements.

Table 5-1 and **Table 5-2** below present an example Appraisal Summary Table and sensitivity test output adhering to CBA carbon reporting requirements.

Table 5-1: Example Reporting - Appraisal Summary Table

Decision metric element	Option 1 (P50)	Option 1 (P90)
Costs		
Base estimate (\$m)		
Contingency (\$m)		
Cost escalation (\$m)		
IPE overhead (\$m)		
Outturn cost (\$m)		
Operating and other cost (\$m)		
Total cost used in economic appraisal (PV, \$m)		
Benefits		
Travel Time Savings (\$m, PV)		
Vehicle Operating Cost Savings (\$m, PV)		
Safety Benefits (\$m, PV)		
Embodied Upfront Carbon Emissions, A1-A5 (\$m, PV)		
In-Use, Operational and User Carbon Emissions (\$m, PV)		
Other environmental impacts (\$m, PV)*		
Construction Disruption Impact (\$m, PV)		
Residual value (\$m, PV)		
Total benefits (\$m, PV)		
Results	Core Analysis (P50 Cost @5% Discount Rate)	Core Analysis (P90 Cost @5% Discount Rate)
BCR		
NPV (\$m)		

*all user and in-use environmental impacts including direct tail-pipe and well-to-tank emissions

Table 5-2: Example Reporting - Sensitivity Test

Sensitivity Scenario	BCR	NPV
3% Discount Rate		
7% Discount Rate		
10% Discount Rate		
+20% Benefits		
-20% Benefits		
+20% Costs		
-20% Costs		
NSW High Carbon Value (Upper-Bound)		
National Carbon Value - Central Estimate		
National Carbon Value - (Lower-Bound)		

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Appendix A: Worked example using Asset Level Carbon Intensity Benchmarks (ALCIB)

The below worked example is of a road project where the carbon emissions of the project option are assessed relative to the base case. This worked example is hypothetical only and aims to demonstrate the practical application of the approach presented in this guidance document. Note that while projects will have at least two options in a business case, this example assesses only one option for demonstrative purposes.

In this worked example, the project option is for the implementation of transport infrastructure and has impacts on the network Vehicle Kilometers Travelled (VKT).

Key steps are as follows:

- Step 1: Estimate the carbon emissions in the base case.
- Step 2: Estimate the carbon emissions in the project case.
- Step 3: Calculate the incremental carbon emissions of each project option.
- Step 4: Monetise and report the results.

Step 1: Estimate the carbon emissions in the base case

Upfront embodied carbon emissions:

If no additional infrastructure is proposed for the base case, the baseline for upfront carbon will be zero. While there may be an existing road or other transport infrastructure asset, the embodied carbon of existing assets should be considered as 'sunk' and not included in the analysis.

In the case of this worked example, the base case proposes the status-quo as the do-minimum with no capital spend on additional infrastructure. As such, the upfront carbon in the base case is zero.

In-use carbon emissions:

For many transport projects, there is often limited data available to support detailed estimation of carbon emissions associated with in-use phases (Modules B1–B5) and operational energy and water use (Modules B6–B7). Where these emissions are not quantified, they should still be considered qualitatively to inform option development and trade-off analysis.

At the time of writing this technical note, no officially recognised methodology exists for estimating these modules within the context of transport CBA. As such, no standard calculation method is provided here. However, practitioners are encouraged to develop robust, project-specific methodologies where data is available and the effort is proportionate to the project's scope.

One practical approach is to estimate emissions using fixed emissions benchmarks (e.g. kg CO₂e per dollar of maintenance expenditure), in combination with the project's anticipated maintenance and operational profiles over the appraisal period.

User carbon:

"User Carbon" emissions are measurable in the base case through traffic modelling outputs. These emissions occur throughout the appraisal period (referred to as B8 emissions in

Figure 1) and are measured in two, additive, components:

- 1. “Climate change” (or user direct) carbon emissions which are directly produced by vehicles during their operation, also known as ‘tailpipe emissions’ (parameters provided in **Table 3-3** and **Table 3-4**)
- 2. “Well-to-tank” (or user indirect) carbon emissions which are associated with the production, refining, and transportation of fuel before it is consumed by vehicles (parameters provided in **Table 3-5** and **Table 3-6**). These emissions comprise predominantly carbon emissions and a smaller component of air pollution. It should be noted that while these emissions occur upstream of user tailpipe emissions, they are attributable to vehicle use (VKT) rather than the built asset itself, and are therefore considered separate from the asset’s embodied emissions.

In this example, emissions are converted directly from VKT to emissions values using the TfNSW EPV tables referenced above. The following formula is used to estimate the User Carbon Emissions:

Equation 1: User Carbon emissions calculation (\$million)

$$User\ Carbon\ Emissions_{bc} = \sum_{t=1}^T (VKT_t \times TE_t) + \sum_{t=1}^T (VKT_t \times WTT_t)$$

Where:

$User\ Carbon\ Emissions_{bc}$ = total user carbon emissions in the base case (\$million)

T = the total number of years in the appraisal period

t = each individual year in the appraisal period

VKT_t = the vehicle kilometres travelled in year “t”

TE_t = the tailpipe emissions conversion per “VKT” in year “t”

WTT_t = the Well-to-Tank emissions per “VKT” in year “t”

Table A-1 sets out the parameters used for the equation above. These are drawn from traffic modelling outputs and parameter values from this document. Note that parameters drawn from **Table 3-3** and **Table 3-5** need to be adjusted to the year of emissions using the factor adjustment **Table 3-2**.

Table A-1: Parameters for User Carbon calculation (Base case)

Parameter	Value	Source
Number of years in the appraisal period	33	CBA assumption
Million Vehicle Kilometres Travelled (MVKT) in year (example year 2026)	359.6	Traffic modelling output
Value of Tailpipe emissions per VKT (cents/VKT)	2.47	Table 3-3
Well-to-tank emissions per VKT	0.51	Table 3-5

The results are calculated for each year of the appraisal period to derive the nominal value of emissions. Values are discounted back to the base year of the analysis to derive the Present Value of emissions. A breakdown of the results are provided below in **Table A-2**.

Table A-2: Base case user carbon emissions (B8)

Module/Scenario	Nominal (\$million)	Present Value (2024/25) (\$million)
Total value of tail pipe emissions	780.5	328.7
Total value of Well-to-tank emissions	162.3	68.3
Total value of User Carbon emissions	943.3	397.0

Step 2: Estimate the carbon emissions in the project case

Upfront Embodied Carbon:

For the project option, new transport infrastructure is proposed, hence the presence of measurable upfront embodied carbon emissions.

For this worked example, the Asset Level Carbon Intensity Benchmark method was used.

Equation 2: Upfront Embodied Carbon emissions calculation (tonnes)

$$Embodied\ Carbon\ Emissions_{pc} = \sum_{t=1}^T [EXP_t \times MS(EI_{A1-A3} + EI_{A4} + EI_{A5})]$$

Where:

$Embodied\ Carbon\ Emissions_{pc}$ = total upfront embodied carbon emissions in the project case (tonnes)

T = the total number of years in the appraisal period

t = each individual year in the appraisal period

EXP_t = annual capital expenditure for year “t”

MS = the material share of capital expenditure as stated in ALCIB

$EI_{A1-A3} / EI_{A4} / EI_{A5}$ = emission intensities for product stages A1 to A5 respectively

First, the amount of embodied carbon (in tonnes) was estimated for each year over the appraisal period. The emission volume was then multiplied with the corresponding carbon value for the year of emissions to determine the nominal value of emissions. The parameters used for this are provided in

Table A-3 below. Note the Capital expenditure and value of carbon emission is different for each year of the appraisal period. 2024/25 financial year is provided for example values.

Table A-3: Parameters for Upfront Carbon calculation (Project Case)

Parameter	Value	Source
Number of years in appraisal period	33	CBA assumption
Capital Expenditure (example year 2024/25) (million)	\$103.00	CAPEX expenditure profile estimates
Material share of expenditure (state road typecast)	20%	Asset Level Carbon Intensity Benchmark
Emission intensity A1-A3 (kg emission per \$ material spend)	0.432	Asset Level Carbon Intensity Benchmark
Emission intensity A4 (kg emission per \$ material spend)	0.036	Asset Level Carbon Intensity Benchmark
Emission intensity A5 (kg emission per \$ material spend)	0.180	Asset Level Carbon Intensity Benchmark
Value of carbon emissions (example year 2024/25) (\$/tonne)	135.74	Table 3-1

The nominal Upfront Embodied Carbon emission values were then discounted at 5% back to the base year of the appraisal (2024/25) to determine the Present Value of emissions. A summary breakdown of the total upfront embodied carbon emissions and emission values is provided in **Table A-4** below.

Table A-4: Upfront embodied carbon emissions

Source	2024/25	2025/26	2026/27	Total
Capital expenditure (\$million)	102.00	170.00	68.00	340.00
A1-A3 (Raw material supply, Transport & Manufacturing) (tonnes CO ₂ -e)	10,547	17,578	7,031	35,156
A4 (Transport) (tonnes CO ₂ -e)	877	1462	585	2924
A5 (Construction) (tonnes CO ₂ -e)	4,386	7,310	2,924	14,620
Value of Upfront Embodied Emissions (\$million, nominal)	2.15	3.60	1.46	7.21
Value of Upfront Embodied emissions (\$million, PV)	2.04	3.27	1.26	6.58

**A1-A3 should be separated out where possible, however sometimes this is not possible given the emissions estimation approach, and must be grouped together (this is also represented as "Cradle to Gate" emissions)*

In-use carbon emissions:

The process and calculation for In-use carbon emissions in the project case should be the same as the base case (set out in Step 1 above).

User carbon:

The process and calculation approach for user carbon emissions in the project case is the same as the base case (as demonstrated above in Step 1). The amount of user carbon emitted over the appraisal period has been calculated based on the forecast network VKT in the project case. The carbon values applied are the same as the base case, however as there is a lower forecast VKT in the project case, the emission estimates are lower compared to the base case. Results shown in **Table A-5** demonstrate the reduction in emissions and subsequently the emission value.

Table A-5: Project options user carbon emissions (B8) (tonnes CO₂-e)

Module/Scenario	Nominal (\$million)	Present Value (2024/25) (\$million)
Total value of tail pipe emissions	773.1	325.9
Total value of Well-to-tank emissions	160.8	67.8
Total value of User Carbon emissions	933.9	393.6

Step 3: Calculate the incremental carbon emissions

By comparing the base case with the project case, incremental carbon emissions can be estimated.

In this example, the embodied carbon emissions amount and year is set to align with the capital spend over the construction period; the in-use carbon emissions would be aligned with the forecast maintenance expenditure in the base case and project case; and the user carbon is linked to anticipated VKT in the network, increasing with traffic demand over the appraisal period. Emission quantities are interpolated between modelled years with travel demand growth held constant from the final modelling year. **Table A-6** shows the total incremental embodied and user carbon emissions.

Table A-6: Incremental Carbon Emissions

Module/Scenario	Base case (tonnes CO ₂ -e)	Project Case (tonnes CO ₂ -e)	Incremental (tonnes CO ₂ -e)	Percentage of total**
Products (A1-A3)	-	35,156	35,156	45.1%
Transport (A4)	-	2,924	2,924	3.8%
Construction (A5)	-	14,620	14,620	18.8%
Total Upfront Embodied Carbon (A1-A5)	-	52,700	52,700	67.6%
Total In-Use Carbon (B1-B5)	<i>Not estimated</i>	<i>Not estimated</i>	<i>Not estimated</i>	<i>Not estimated</i>
Total User Carbon (B8)*	2,965,418	2,940,131	-25,287***	-32.4%
Total carbon emissions	2,965,418	2,992,831	27,413	-

*the quantity (tonnes) of User Carbon emissions was calculated by converting the nominal value of emissions to tonnes using carbon value per tonne for each year over the appraisal period.

**representative of absolute values.

***this represents a net reduction in emissions

Step 4: Monetise and report carbon emissions

It is important to estimate what year the carbon emissions are expected to occur as this will impact the carbon value used for CBA analysis.

To monetise the incremental carbon benefit / disbenefit, the carbon value from **Table 3-1** was adjusted using the adjustment factors in **Table 3-2** to determine the carbon value for the core analysis and sensitivity tests for each year of the appraisal period. These values were then multiplied by the incremental carbon emissions for each year of the appraisal period (calculated in Step 3) to estimate the total carbon impact for Upfront Embodied, In-Use and User Carbon.

These values were discounted at a rate of 5% to derive a Present Value (PV) of the carbon impact of the project option.

Table A-7: Results of carbon analysis

Module/Scenario	NSW Carbon Value (Core Analysis)	NSW High Carbon Value (Upper-Bound)	National Carbon Value - Central Estimate	National Carbon Value - (Lower- Bound)
Total Value of Carbon Emissions (\$Nominal, million)				
Upfront Embodied Carbon (A1-A5)	-7.21	-12.72	-4.24	-3.46
In-use, Operational and User Carbon emissions (B1-B8)	8.93	16.14	8.48	6.47
Total	1.71	3.43	4.24	3.00
Total Value of Carbon Emissions (\$PV, 2024, million)				
Upfront Embodied Carbon (A1-A5)	-6.58	-11.60	-3.85	-3.15
In-use, Operational and User Carbon emissions (B1-B8)	3.35	5.86	3.03	2.30
Total	-3.22	-5.74	-0.82	-0.85

Notes: A positive value represents a benefit while a negative value represents a disbenefit. In the AST – these values would be reported in addition to “Other environmental externalities” as a separate line item.

Interpretation of results and Impact on BCR and other decision metrics

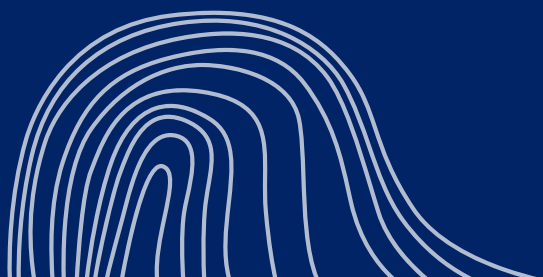
The results demonstrate that, over the appraisal period, the disbenefit from Upfront Embodied Carbon emissions amounts to \$7.21 million. However, this is outweighed by a User Carbon and In-use Carbon emission benefit of \$8.93 million, primarily driven by the reduction in Vehicle Kilometers Traveled (VKT). This results in a net benefit of \$1.71 million in nominal terms. This outcome is expected for projects that result in shorter trips and a subsequent decrease in VKT. Conversely, for projects that have no impact on VKT (or an increase in VKT), the net disbenefit in both nominal and real terms would be more significant.

In Present Value (PV) terms, the disbenefit from Upfront Embodied Carbon is \$6.58 million. This is counterbalanced by an In-use Carbon and User Carbon emission benefit of \$3.35 million, resulting in a net PV disbenefit of \$3.22 million. The lower impact of the In-use and User Carbon in PV terms is due to the most significant impacts occurring later in the appraisal period, which are more heavily affected by discounting.

The final step is to incorporate the results into the wider CBA analysis and decision metrics. This entails increasing the net benefit of the project if the carbon impact is positive and decreasing the net benefit of the project if the carbon impact is negative.

As this worked example represents the valuation of carbon in isolation, a BCR and other decision metrics are not presented.

Projects with a high material share of capex or exceptionally carbon intensive production/materials are expected to have a more significantly impacted BCR when whole of life carbon is included in the CBA analysis.



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