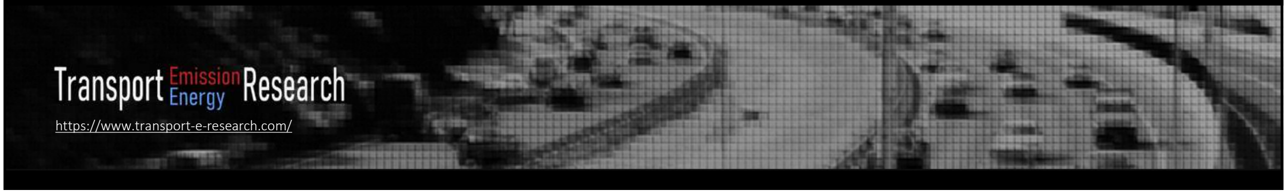
Assessing lifecycle and mode shift impacts on greenhouse gas emissions in the Australian transport sector

iMOVE National R&D Conference
OUR FUTURE FREIGHT
25 October 2024, Brisbane

Dr Robin Smit, Founding Director TER + Adjunct Professor University of Technology Sydney



Transport Emission Energy Research
https://www.transport-e-research.com/

Life Cycle Assessment (LCA)

Transport Emission Energy Research

- Systematic evaluation of all aspects of a vehicle's life and its associated impacts (cradle-to-grave).
    - Energy cycle (well-to-wheel/wake/wing)
        - Fuel or electricity production and distribution
        - Vehicle operation and maintenance
    - Vehicle cycle
        - Vehicle manufacturing
        - Disposal and recycling
- Several impacts → GHG (our studies)

Life Cycle Assessment (LCA)

Transport Emission Energy Research

- Four elements of study design to ensure reliable and robust results:

● country-specific ● mode-specific

  - ○ robust LCA/mode shift data for Australian transport limited
  - ○ demonstrate Australian emission tools

● wide scope ● time-dynamic

  - ○ modelling framework where results can be rapidly updated.

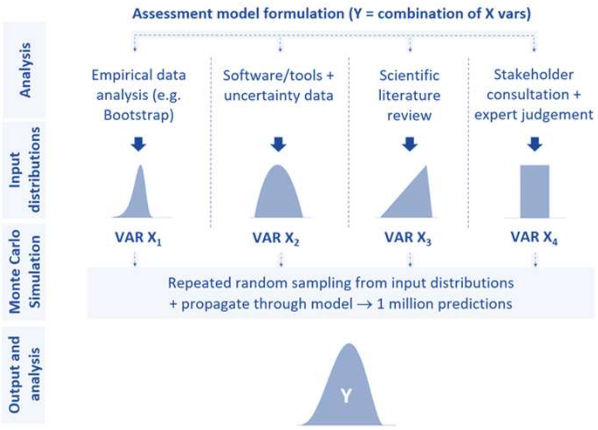
Statistical modelling

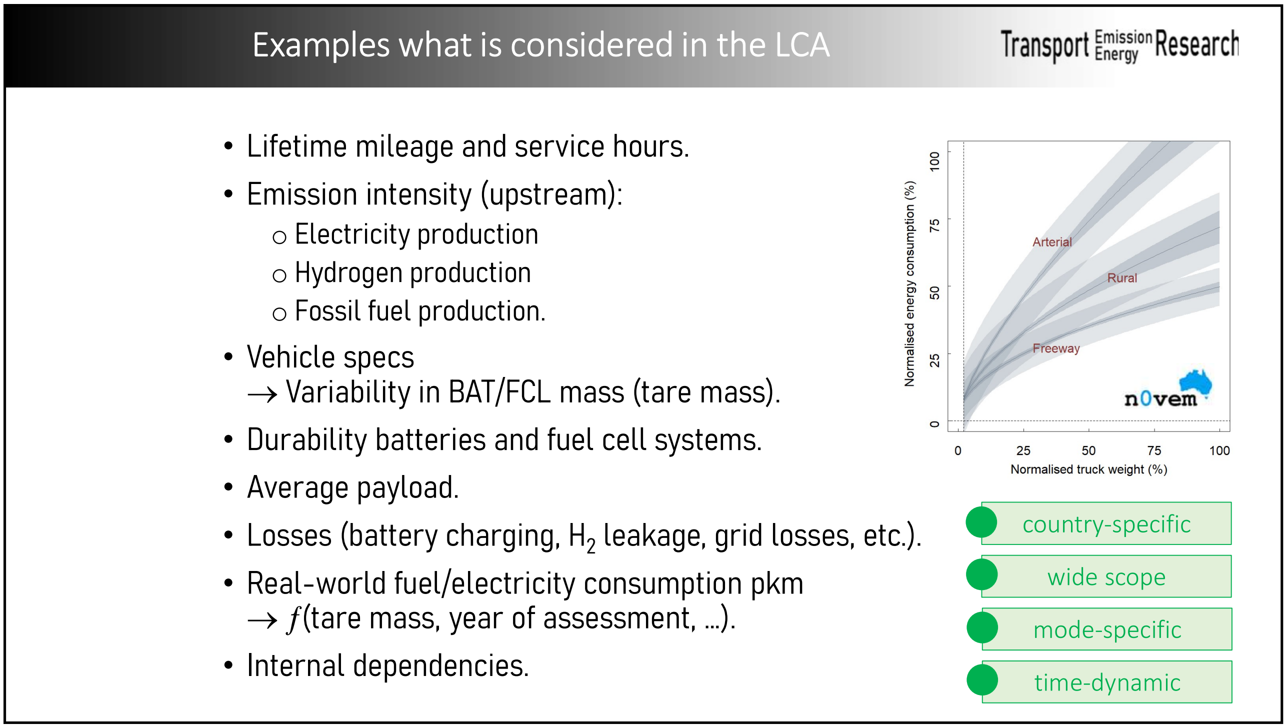
Transport Emission Energy Research

● wide scope

● time dynamic

- Include uncertainty/variability in inputs + reflect them in the outputs.
  - ○ plausible range
  - ○ robustness
  - ○ sensitivity.





Examples what is considered in the LCA

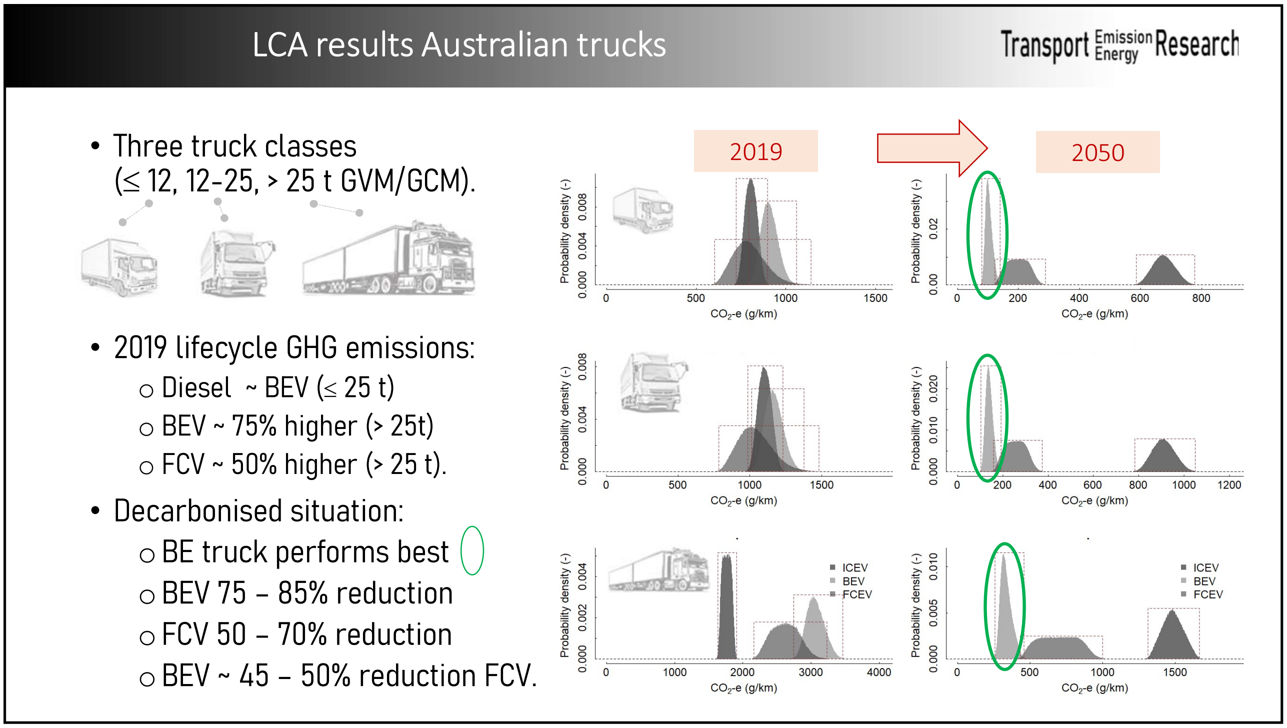
- Lifetime mileage and service hours.
- Emission intensity (upstream):
  - ○ Electricity production
  - ○ Hydrogen production
  - ○ Fossil fuel production.
- Vehicle specs
  → Variability in BAT/FCL mass (tare mass).
- Durability batteries and fuel cell systems.
- Average payload.
- Losses (battery charging, H_2 leakage, grid losses, etc.).
- Real-world fuel/electricity consumption pkm
  → f(tare mass, year of assessment, …).
- Internal dependencies.

● country-specific

● wide scope

● mode-specific

● time-dynamic



LCA results Australian trucks

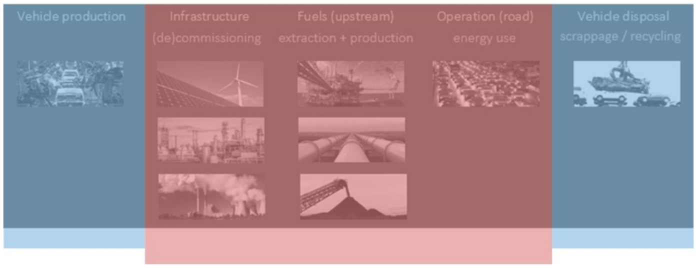
- Three truck classes
  (≤ 12, 12-25, > 25 t GVM/GCM).
- 2019 lifecycle GHG emissions:
  - ○ Diesel ~ BEV (≤ 25 t)
  - ○ BEV ~ 75% higher (> 25t)
  - ○ FCV ~ 50% higher (> 25 t).
- Decarbonised situation:
  - ○ BE truck performs best
  - ○ BEV 75 – 85% reduction
  - ○ FCV 50 – 70% reduction
  - ○ BEV ~ 45 – 50% reduction FCV.

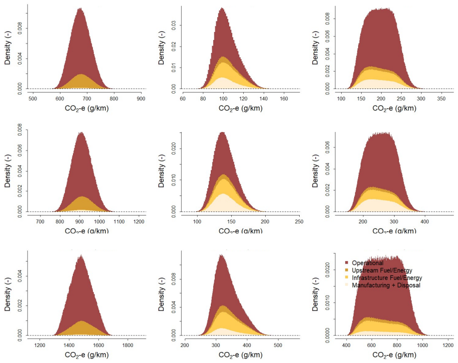
2019

2050

LCA results Australian trucks

Transport Emission Energy Research



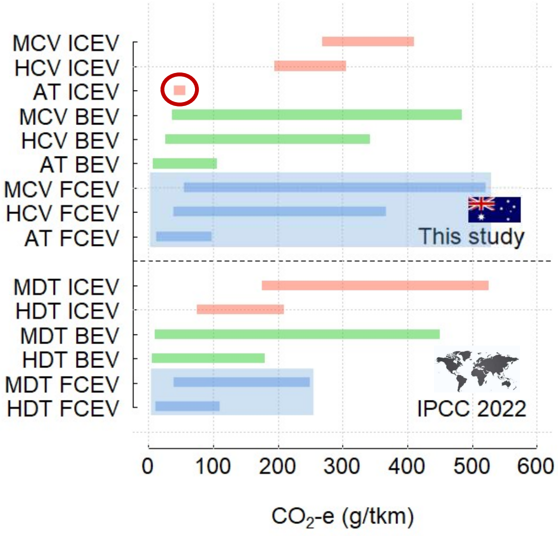


- Vehicle cycle
    - 1-5% (ICEV)
    - 5-25% (EV)
    - disposal/recycling < 1%.
- Energy cycle
    - 75-99% of lifecycle emissions
    - operational emissions dominate lifecycle emissions, 50-85%.

Comparison to international studies

Transport Emission Energy Research

- Results ~ align with IPCC lifecycle emissions for freight trucks.
- ○: low emission intensity heavy articulated trucks.
- 🟦: wider range hydrogen trucks
  → elevated uncertainty
  → they can produce the *highest* emission intensity.



Open access papers

2022

sustainability

MDPI

Article

Greenhouse Gas Emissions Performance of Electric and Fossil-Fueled Passenger Vehicles with Uncertainty Estimates Using a Probabilistic Life-Cycle Assessment

Robin Smit * and Daniel William Kennedy

Transport Energy/Emission Research (TER), Brisbane, QLD 4068, Australia; info@transport-e-research.com
* Correspondence: robin.smit@transport-e-research.com

Abstract: A technology assessment is conducted for battery electric and conventional fossil-fueled passenger vehicles for three Australian scenarios and seven Australian states and territories. This study uses a probabilistic life-cycle assessment (pLCA) to explicitly quantify uncertainty in the LCA inputs and results. Parametric input distributions are developed using statistical techniques. For the 2018 Australian electricity mix, which is still largely fossil fuels based, the weight of evidence suggests that electric vehicles will reduce GHG emission rates by 29% to 41%. For the 'fossil fuels only' marginal electricity scenario, electric vehicles are still expected to significantly reduce emission rates by between 10% and 32%. Large reductions between 74% and 80% are observed for the more renewables scenario. For the Australian jurisdictions, the average LCA GHG emission factors vary substantially for conventional vehicles (364–390 g CO_2-e/km), but particularly for electric vehicles (98–287 g CO_2-e/km), which reflects the differences in fuel mix for electricity generation in the different states and territories. Electrification of the Tasmanian on-road fleet has the largest predicted fleet average reduction in LCA greenhouse gas emissions of 243–300 g CO_2-e/km. A sensitivity analysis with alternative input distributions suggests that the outcomes from this study are robust.

Keywords: motor vehicle; greenhouse gas emissions; battery electric; life cycle; LCA; Monte Carlo; bootstrap; truncated distribution; BEV; ICEV

check for updates

Citation: Smit, R.; Kennedy, D.W. Greenhouse Gas Emissions Performance of Electric and Fossil-Fueled Passenger Vehicles with Uncertainty Estimates Using a Probabilistic Life-Cycle Assessment. *Sustainability* **2022**, *14*, 3444. https://doi.org/10.3390/su14063444

Academic Editor: Eckard Helmers

Received: 4 February 2022
Accepted: 9 March 2022
Published: 15 March 2022

1. Introduction

To properly assess greenhouse gas (GHG) emissions performance of different vehicle technologies, a holistic and systematic method is required that evaluates all aspects of a vehicle's life and its associated impacts (cradle-to-grave). Life-cycle assessment or LCA is a method used to quantify the environmental impacts of a product's manufacture, operational use and end-of-life [1]. LCA can help clarify potential trade-offs between different environmental impacts and between different stages of the life cycle [2]. The comprehensive scope of LCA is useful in avoiding problem shifting from one life-cycle phase to another, from one region to another, or from one environmental problem to another [3].

There are different types of environmental impacts that can be assessed with LCA such as GHG emission impacts, toxicity, mineral resource depletion and land use [4,5]. Given the complexity and detailed consideration of the various aspects of a vehicle's life, LCA studies often incur restrictions in scope. For instance, LCA studies can focus on specific environmental impacts (e.g., greenhouse gas emissions only) or have a broader consideration of environmental impacts but focus on a few specific vehicle makes/models [5,6]. LCA studies can be set up in different ways, naturally with several underlying assumptions. LCA considers processes that are complex, location specific and vary in time, as well as over time (trends). It is therefore not surprising that LCA studies have caused diverging arguments about the environmental performance of the technology that is assessed [4,7]. Significant differences in LCA results have been reported for similar electricity generation

Sustainability **2022**, *14*, 3444. https://doi.org/10.3390/su14063444 https://www.mdpi.com/journal/sustainability

2024

sustainability

MDPI

Article

Greenhouse Gas Emissions Performance of Electric, Hydrogen and Fossil-Fuelled Freight Trucks with Uncertainty Estimates Using a Probabilistic Life-Cycle Assessment (pLCA)

Robin Smit [1,*], Eckard Helmers [2], Michael Schwingshackl [3], Martin Opetnik [4] and Daniel Kennedy [1]

[1] Transport Energy/Emission Research (TER), Launceston, TAS 7249, Australia
[2] Environmental Planning and Technology Department, University of Applied Sciences Trier, Umwelt Campus Birkenfeld, P.O. Box 1380, 55761 Birkenfeld, Germany; e.helmers@umwelt-campus.de
[3] Footprint-Consult e.U., 3335 Weyer, Austria; office@footprint-consult.com
[4] Institute of Thermodynamics and Sustainable Propulsion Systems, Graz University of Technology, 8010 Graz, Austria
* Correspondence: robin.smit@transport-e-research.com

Abstract: This research conducted a probabilistic life-cycle assessment (pLCA) into the greenhouse gas (GHG) emissions performance of nine combinations of truck size and powertrain technology for a recent past and a future (largely decarbonised) situation in Australia. This study finds that the relative and absolute life-cycle GHG emissions performance strongly depends on the vehicle class, powertrain and year of assessment. Life-cycle emission factor distributions vary substantially in their magnitude, range and shape. Diesel trucks had lower life-cycle GHG emissions in 2019 than electric trucks (battery, hydrogen fuel cell), mainly due to the high carbon-emission intensity of the Australian electricity grid (mainly coal) and hydrogen production (mainly through steam–methane reforming). The picture is, however, very different for a more decarbonised situation, where battery electric trucks, in particular, provide deep reductions (about 75–85%) in life-cycle GHG emissions. Fuel-cell electric (hydrogen) trucks also provide substantial reductions (about 50–70%), but not as deep as those for battery electric trucks. Moreover, hydrogen trucks exhibit the largest uncertainty in emissions performance, which reflects the uncertainty and general lack of information for this technology. They therefore carry an elevated risk of not achieving the expected emission reductions. Battery electric trucks show the smallest (absolute) uncertainty, which suggests that these trucks are expected to deliver the deepest and most robust emission reductions. Operational emissions (on-road driving and vehicle maintenance combined) dominate life-cycle emissions for all vehicle classes. Vehicle manufacturing and upstream emissions make a relatively small contribution to life-cycle emissions from diesel trucks (<5% each), but these are important aspects for electric trucks (5% to 30%).

Keywords: truck; HDV; freight; greenhouse gas emissions; GHG; battery electric; fuel cell; hydrogen; carbon footprint; life cycle; LCA; probabilistic; BEV; ICEV; FCEV

check for updates

Citation: Smit, R.; Helmers, E.; Schwingshackl, M.; Opetnik, M.; Kennedy, D. Greenhouse Gas Emissions Performance of Electric, Hydrogen and Fossil-Fuelled Freight Trucks with Uncertainty Estimates Using a Probabilistic Life-Cycle Assessment (pLCA). *Sustainability* **2024**, *16*, 0. https://doi.org/

Academic Editor: Ocktaeck Lim

Received: 21 November 2023
Revised: 20 December 2023
Accepted: 8 January 2024
Published: 15 January 2024

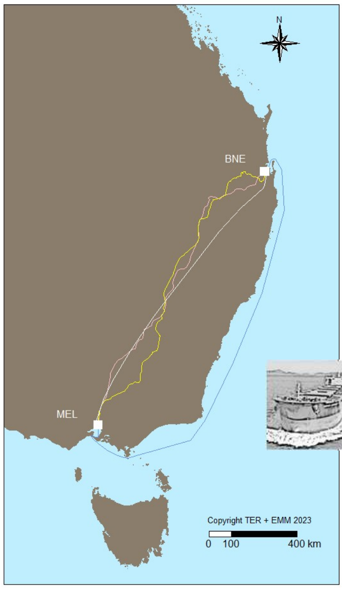
1. Introduction

Road transport contributes significantly to total greenhouse gas emissions, and this contribution is growing. In Australia, the contribution is currently 16% [1], but in the EU, it is already the largest source, contributing 30% to total greenhouse gas (GHG) emissions [2]. Unlike the other sectors, the transport sector proves particularly resistant to decoupling from economic growth [3], which is why addressing its relatively poor GHG emissions performance needs to be given special priority. Despite their small share of total stravel, heavy-duty vehicles are typically responsible for about 25% of total road transport emissions, and their relative contribution is growing [2,4,5].

Sustainability **2024**, *16*, 0. https://doi.org/10.3390/su16020000 https://www.mdpi.com/journal/sustainability

Australian mode shift research study

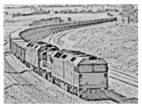
- country-specific
- wide scope
- time dynamic
- mode-specific



Passenger vehicle (cars, SUVs) + power-train technology mix

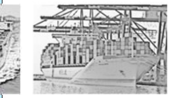
High-speed train

Long-haul truck (B-Double) + power-train technology mix



Freight train (diesel or electric)

⛽ ⚡



Bulk carrier (45/75 kt DWT) or container ship (2700/4500 TEU)

Narrow-body single-aisle aircraft (A320/B737)

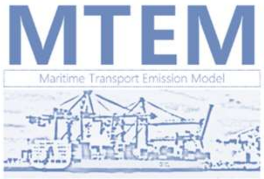
Mode + country specific modelling

Transport Emission Energy Research

AFM
Australian fleet model

copert
AUSTRALIA

n0vem

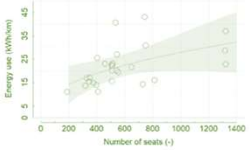


Road

Sea

Air

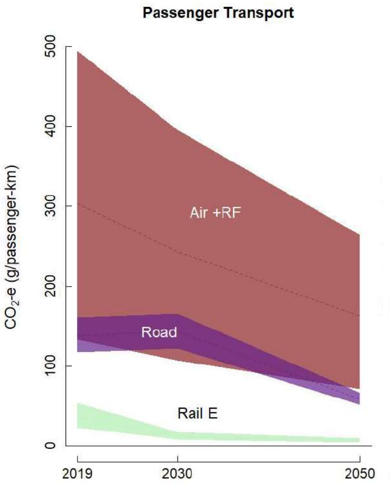
Rail

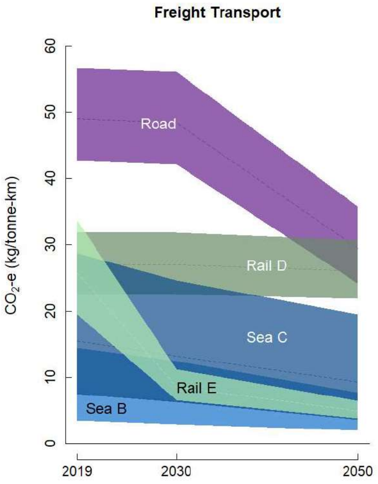


Intermodal comparison passenger transport

Transport Emission Energy Research

- E-rail deep and robust GHG emission reductions.
- Shipping low but more variable/ uncertain.
- Different decarbonisation trajectories → cumulative emissions.





Note: aircraft not included
→ far outside GHG scale
(up to a factor 100).

Open access papers

ORIGINAL RESEARCH ARTICLE

Impacts of mode shift on well-to-wheel emissions from inter-capital transport in Australia – Part I: Road and rail transport

Robin Smit[1,2*], Paul Graeme Boulter[3]

Show Less

[1] Transport Energy/Emission Research (TER), Launceston, Tasmania, Australia
[2] Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, Australia
[3] EMM Consulting, St. Leonards, New South Wales, Australia

EER **2024**, 1(1), 3470 https://doi.org/10.36922/eer.3470
Submitted: 23 April 2024 | Accepted: 27 June 2024 | Published: 26 July 2024

ORIGINAL RESEARCH ARTICLE

Impacts of mode shift on well-to-wheel emissions from inter-capital transport in Australia – Part II: Sea and air transport

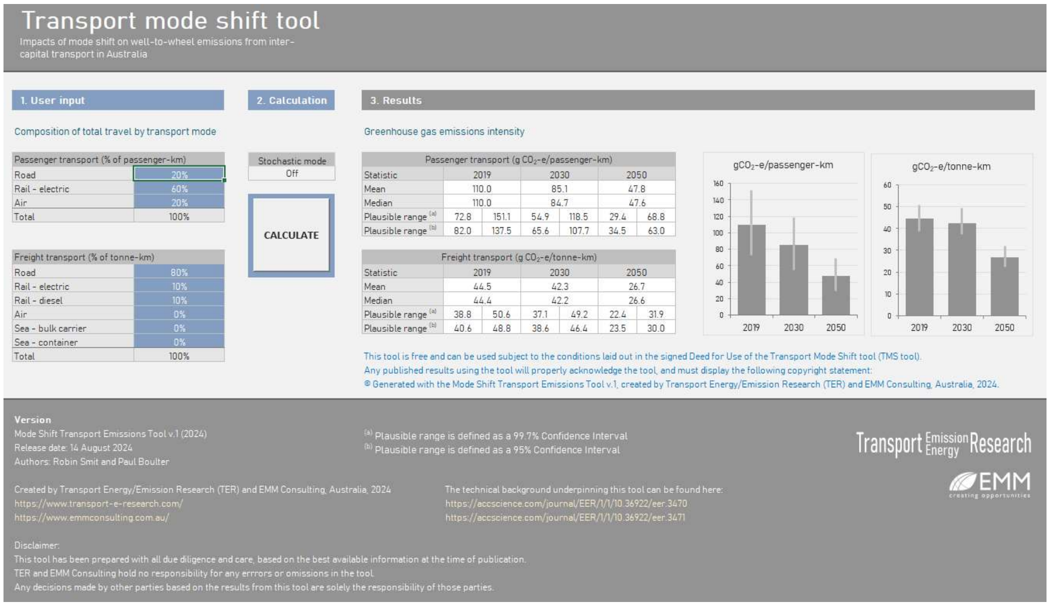
Robin Smit[1,2*], Paul Graeme Boulter[3]

Show Less

[1] Transport Energy/Emission Research, Launceston, TAS, Australia
[2] Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, Australia
[3] EMM Consulting, St. Leonards, New South Wales, Australia

EER **2024**, 1(1), 3471 https://doi.org/10.36922/eer.3471
Submitted: 23 April 2024 | Accepted: 27 June 2024 | Published: 26 July 2024

https://www.transport-e-research.com/publications



Transport mode shift tool

Impacts of mode shift on well-to-wheel emissions from inter-capital transport in Australia

1. User input

Composition of total travel by transport mode

Passenger transport (% of passenger-km)	
Road	20%
Rail - electric	60%
Air	20%
Total	100%

Freight transport (% of tonne-km)	
Road	80%
Rail - electric	10%
Rail - diesel	10%
Air	0%
Sea - bulk carrier	0%
Sea - container	0%
Total	100%

2. Calculation

Stochastic mode: Off

3. Results

Greenhouse gas emissions intensity

Passenger transport (g CO_2-e/passenger-km)

Statistic	2019		2030		2050	
Mean	110.0		85.1		47.8	
Median	110.0		84.7		47.6	
Plausible range [a]	72.8	151.1	54.9	118.5	29.4	68.8
Plausible range [b]	82.0	137.5	65.6	107.7	34.5	63.0

Freight transport (g CO_2-e/tonne-km)

Statistic	2019		2030		2050	
Mean	44.5		42.3		26.7	
Median	44.4		42.2		26.6	
Plausible range [a]	38.8	50.6	37.1	49.2	22.4	31.9
Plausible range [b]	40.6	48.8	38.6	46.4	23.5	30.0

This tool is free and can be used subject to the conditions laid out in the signed Deed for Use of the Transport Mode Shift tool (TMS tool).
Any published results using the tool will properly acknowledge the tool, and must display the following copyright statement:
© Generated with the Mode Shift Transport Emissions Tool v.1, created by Transport Energy/Emission Research (TER) and EMM Consulting, Australia, 2024.

Version
Mode Shift Transport Emissions Tool v.1 (2024)
Release date: 14 August 2024
Authors: Robin Smit and Paul Boulter

[a] Plausible range is defined as a 99.7% Confidence Interval
[b] Plausible range is defined as a 95% Confidence Interval

Created by Transport Energy/Emission Research (TER) and EMM Consulting, Australia, 2024
https://www.transport-e-research.com/
https://www.emmconsulting.com.au/

The technical background underpinning this tool can be found here:
https://accscience.com/journal/EER/1/1/10.36922/eer.3470
https://accscience.com/journal/EER/1/1/10.36922/eer.3471

Disclaimer:
This tool has been prepared with all due diligence and care, based on the best available information at the time of publication.
TER and EMM Consulting hold no responsibility for any errrors or omissions in the tool.
Any decisions made by other parties based on the results from this tool are solely the responsibility of those parties.

Transport Emission Energy Research

Thank you for your time.

robin.smit@transport-e-research.com