Supplementary material

Life Cycle Sustainability Assessment of Alternative Energy Sources for the Western Australian transport sector

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Section A: Fuel Selection

The reasons for selecting ethanol, electricity and hydrogen fuel for WA are summarized in this section. The section also describes the reasons for not selecting biogas, natural gas and LPG as a transport fuel for the state.

1. Ethanol

As mentioned in the manuscript, the gasoline-ethanol blend E65 is considered as the base case for the study. Three potential feedstocks, such as wheat (E10), cereal straw (E53) and Mallee (E2) are used to produce E65 due to their availability in WA.

Wheat: WA produces around 10 million tonnes of wheat every year and 95% of this is exported [1]. Whereas, only 0.57 million tonnes of wheat is required for producing the E10 to meet the state requirements (**Eq. 1** and **2**) without affecting the food supply chain [2]. Around 6.6% of total gasoline requirement in WA can be replaced with this E10 (**Eq. 3**).

Amount of ethanol = Ethanol conversion rate × Amount of feedstock (1)

Possible ethanol blend in WA=

(Amount of ethanol ÷ Gasoline requirement of WA) *100 (2)

Percentage of gasoline replacement in WA= Ethanol blend ÷ ratio of calorific value of gasoline to calorific value of ethanol (3)

Where, Amount of feedstock = 0.57 M tonnes, ethanol conversion rate from wheat = 400 L/tonne [3], gasoline requirement of WA = 2262 ML [4], ratio of calorific value of gasoline to calorific value of ethanol = 1.51 [5].

Cereal straw:

Around 5.157 million tonnes of straw is available in WA for ethanol production [2]. The amount of ethanol blend E53 is calculated using the **Eq. 1, 2** and **3** as below:

Ethanol blend = (5.157×231.48 ÷ 2262) ×100 ≈ E53, which is equivalent to 35% gasoline replacement in WA.

Where, ethanol conversion rate from straw = 231.48 Litre/tonne based on the 25% moisture content of straw [2, 6].

Mallee:

Around 0.259 million tonnes of Mallee resources are currently available in WA [2, 7] that could generate 1.3% (E 2) of gasoline replacement in WA [2] (based on **Eq**. **1, 2** and **3**).

Amount of ethanol= 259÷5.80= 45 ML

Ethanol blend from Mallee = (45 ÷ 2262) ×100 ≈ E2, which is equivalent to 1.3% gasoline replacement in WA.

Where, Ethanol conversion rate from Mallee= 5.80 kg/L [2, 6]

Corn, grain sorghum and sugarcane are the other three popular sources of ethanol in the World but the production of those feedstocks in WA is not viable due to the unfavourable climatic conditions [8]. The feedstocks that are produced in the other parts of Australia [9] are not sufficient to bring into WA for ethanol production. Forrest residues, on the other hand, are not considered in this study for ethanol production due to the highly distributed nature of the feedstocks making their collection time consuming and expensive [10, 11].

2. Electricity

Electricity generation mix in WA is comparatively cleaner than the other states of Australia as it comprises 53% natural gas-based and around 7.1% renewable energy-based (mainly solar and wind) electricity. Whereas, the amounts of electricity produced from coal in Victoria, NSW and QLD are 85%, 82% and 65% respectively. The future energy policy of WA also supports the initiatives of electric cars as penetration of more renewable energy in WA's grid is inline as per the policy of the Western Australian Government [12, 13]. It has been estimated that around 37% of electricity would be produced from renewable energy by 2030 in WA. It has been noted that the current electricity grid in WA has a significant amount of surplus that is sufficient to fulfil the fuel needs of as many as 200,000 electric vehicles. This accounts for 10% of all vehicles in WA. A subsidized EV home charging electricity plan during off-peak hours is already available in WA [14]. There are also around 63 charging facilities in different parts of WA [15]. Due to the current potential of EV and PHEV in WA and their increasing use in Australia, they are included in the assessment.

3. Hydrogen

The Western Australian government announced the renewable hydrogen strategy in July 2019 emphasising the need for hydrogen production through WA's renewable wind and solar energy potentials [16]. Excellent wind and solar potential, and skilled workforce are considered as advantages of WA compared to other regions. According to the policy [16]:

- WA government will devise hydrogen regulations, and will support renewable hydrogen production though private sectors,
- Hydrogen refuelling stations for vehicles will be available in WA by 2022,
- Hydrogen will be the significant fuel source for the WA transport sector by 2040.

Hydrogen production through renewable electricity requires water as a feedstock. It has been calculated that only 0.22% of all physical water consumption of WA would be utilized to produce all the hydrogen needed for the state to replace gasoline [2].

4. Biogas

Sewage sludge, animal manure and municipal wastes are the three potential feedstocks for biogas in WA [2, 17, 18]. As these feedstocks are dispersedly located in WA, it would require long-distance transport to carry these feedstocks to chemical plants for biogas production [2, 17]. Electricity production by using biogas seems more feasible from these scattered sources [2, 17].

5. Natural gas and LPG

Natural gas and LPG are also not considered for this study due to the following reasons:

- Sixty-nine percent of Australian natural gas is produced in WA. It has been estimated that the state could run another 97 years from now with its gas reserve. However, proven and probable commercial gas reserves of WA may run out very quickly by 2045 (25 years from now) if they continue utilizing the gas in the same manner as at present [19].
- WA is already in a long-term contract with several companies to export LNG, and 97% of WA's conventional gas reserve is held by the LNG export companies and their joint ventures [20].
- WA government has set a policy to supply only 15% natural gas (of equivalent LNG production) to the WA domestic market. Ninety eight percent (98%) of this gas is used for electricity production, industrial purpose, mining and domestic purposes. Remaining 2% is used for other commercial purposes [19]. Additional around 84 PJ* of natural gas will be required to replace all gasoline in WA. The remaining amount of gas which is available in the domestic market is not sufficient to meet the needs of the transport sector [19]. Besides, to save the WA gas for electricity generation for household and industrial applications seem to be better options than its use for the transport sector. Studies suggest that using natural gas and LPG in vehicles is not the proper way to tackle the energy security and climate change problems [21]. It has been found that CNG vehicles produce more GHG emissions than the coal-fired electricity and oil furnace due to the low-efficiency of gasoline engines [22].

*The gasoline requirement of WA= 2262 ML/year ≈ 2262 M m^3 natural gas/year

= 2.262 billion m^3/year = (2.262/0.027) PJ/year =83.78 PJ/year

Where, 1 L of gasoline is equivalent to 1 m^3 of CNG [23] and 1 PJ = 0.027 billion cubic meters of natural gas [19]

- Unlike natural gas, only a small portion of LPG is produced in WA. In 2016-17, there were only around 800 ML of LPG (both butane and propane) produced in WA [20]. It has been estimated that around 2714.4 ML** of LPG is required to replace all the gasoline requirements of WA. So, the current LPG production in WA is not enough to replace all the gasoline in the WA transport sector. LPG is also used for household and industrial applications in WA. It has also been found that overall LPG production in WA is reduced to about 53% compared to 2010 level, and the current production is the lowest ever in the history of WA since 1999 [20].

- Overall, the current Australian strategic LPG reserve is only for 59 days [24].

**The calculation procedure of 2714.4 ML of LPG requirement to replace all gasoline requirment of WA:

1 Litre gasoline provides mileage equivalent to 1.2 L of LPG [23].
The gasoline requirement of WA= 2262 ML/year
So, LPG requirement = 2262*1.2 =2714.4 ML / year

Section B: Governing equation of indicators

Environmental indicators:

$$GWP/VKT = \sum_{i=1}^{N}(EF_{i\,CO_2} \times I_i + 28EF_{i\,CH_4} \times I_i + 265EF_{i\,N_2O} \times I_i) \quad (4)$$

$$WC/VKT = \sum_{i=1}^{N}(WC_i \times I_i) \quad (5)$$

$$FFD/VKT = \sum_{i=1}^{N}(FFD_i \times I_i) \quad (6)$$

$$LU/VKT = \sum_{i=1}^{N}(LU_i \times I_i \times TO_i) \quad (7)$$

Where, GWP = global warming potential in kgCO_2, $VKT =$ vehicle kilometer travelled, i = life cycle inventory input $(1, 2, 3 \dots \dots N)$ per VKT, I = amount of input, $EF_{i\,CO_2}$= CO_2 emission in kg for an input i , $EF_{i\,CH_4}$= CH_4 emission in kg for an input i , $EF_{i\,N_2O}$= N_2O emission in kg for an input i, WC = water consumption in m^3, WC_i = water consumption for an input i in m^3, FFD = fossil fuel depletion potential in MJ, FFD_i= consumption of fossil fuel for input i in MJ, LU = land use in Ha.a, LU_i = land use for an input i in ha, TO_i= exclusive time of land occupation by input i in years.

Social indicators:

$$Local\ Job\ creations/VKT = \sum_{i=1}^{N}(mh_i \times I_i) + mh_P + mh_{va} \quad (8)$$

Where, i = life cycle inventory input $(1, 2, 3 \dots \dots N)$ which comes from local WA per VKT, mh_i = man-hours required for input i, I = amount of input, mh_P = man-hours required at the alternative fuel production plant to produce 1 km equivalent alternative fuel, mh_{va} = man-hours required at the vehicle assembly plant to assemble 1 km equivalent alternative vehicle.

$$\text{Job creation through electricity} = \mathrm{I_c} \times \mathrm{J_f} \times \mathrm{M} \quad (9)$$

Where, I_c = Installed capacity, J_f = employment factor estimated from Rutovitz et al. [25] and M = multiplier (1 for OECD pacific countries such as Australia for this instance).

$$CFF/VKT = FFD_{af} - FFD_{gasoline} \quad (10)$$

Where, CFF = Conservation of fossil fuel in MJ, FFD_{af} = Fossil fuel use of alternative fuel per VKT in MJ, $FFD_{gasoline}$ = Fossil fuel use of gasoline per VKT in MJ.

Economic indicators:

$$PV = \sum_{i=1}^{i=n} \frac{C \times (1 + IR)^i}{(1 + DR)^i} \quad (11)$$

$$AC = PV \times CRF \quad (12)$$

$$CRF = \frac{(1 + x)^n}{(1 + x)^n - 1} \quad (13)$$

$$LCC/VKT = (AC \div AF) \times FC + AV_{af} \quad (14)$$

Where, i =1 , 2 , 3 …. . n; year value till end of life of the project, C = Present cost (AUD), IR =Inflation rate (3%) and DR= Discount rate (7%) [26], AC = Annualized cost, x = Real discount rate of 3.88% calculated from IR and DR [27], AF = Per unit fuel production annually, FC = Fuel consumption per km, AV_{af} = Additional vehicle cost per km for an alternative fuel compared to gasoline.

$$CRC/VKT = (GHG_{gasoline} - GHG_{af}) * CP \quad (15)$$

Where, CRC = carbon reduction credit per VKT in AUD, $GHG_{gasoline}$ = life cycle GHG emission (kgCO_{2e}) per VKT from gasoline, GHG_{af} = life cycle GHG emission (kgCO_2) from alternative fuel per VKT, CP = Carbon price for per kg GHG emission in AUD.

Section C: Data summary for job creation and economic indicators

Table S1: Job creation through different activities in Mallee plantation and grain farming (by farmers and contractors)

Activities	unit	Job creation (Job-hrs)	remarks
1. Mallee plantation establishment and harvest			
Initial planning of advisor	1 gmt*	2.22E-04	Based on Wu et al [28]
Site inspection by advisor	1 gmt	2.22E-04	Same as above
Site supervision by advisor	1 gmt	2.22E-04	Same as above
Contract marking out and mapping	1 gmt	6.67E-04	Same as above
earthworks by farmer	1 gmt	1.11E-03	Same as above
weed control	1 gmt	1.11E-04	Same as above
monitoring of Mallee seedling production at nursery	1 gmt	2.22E-04	Same as above
transport of seedlings from nursery to site	1 gmt	2.78E-04	Same as above
Planting	1 gmt	1.56E-02	Same as above
monitoring of newly planted seedling	1 gmt	6.67E-04	Same as above
spring weed control	1 gmt	1.11E-04	Same as above
Pesticide	1 gmt	1.11E-04	Same as above
2nd year weed control	1 gmt	1.11E-04	Same as above
Mallee harvest	1 gmt	1.67E-02	Based on Weldegiorgis et al [29]

2. grain farming			
Planting	1 L ethanol	1.58E-04	Based on 0.12 hours/ha [30]
Spraying	1 L ethanol	3.95E-04	Based on 0.03 hours/ha [30]
Harvesting	1 L ethanol	1.05E-04	Based on 0.08 hours/ha [30]
Top dressing	1 L ethanol	1.58E-04	Based on 0.12 hour/ha [31]
3. Others			
Straw harvest	1 L ethnaol	4.97E-05	27% additional time than grain harvest [32]
Straw baling and handling	1 l ethanol	1.84E-04	Assumption based on based on Stucley et al [32]

*green metric tonne of Mallee

Table S2: Data summary for LCC

input	category	unit	Cost (AUD)	Remarks
1. Cost of different inputs				
Flexi N	fertilizer	kg	4.50E-01	Based on local suppliers
Urea	fertilizer	kg	5.30E-01	Same as above
DAP	fertilizer	kg	5.60E-01	Same as above
Lime	chemical	tonne	1.00E+01	Based on department of Agriculture, WA
Glyphosate	Herbicide	L	8.00E+00	Weed control in winter crops 2018 [33]
Crusader	Herbicide	L	7.92E+01	Lupin Agronomy, WA; Elders Technical Site Results. [34]
Gramoxone	Herbicide	L	9.49E+00	Weed control in winter crops 2018 [33]
Logran	Herbicide	kg	2.17E+02	Same as above
MCPA 242	Herbicide	L	1.09E+01	Same as above
Treflan	Herbicide	L	10.00E+00	Lupin Agronomy, WA; Elders Technical Site Results. [34]
Chlorpyrifos	pesticide	L	1.50E+01	Based on local suppliers
Simazine	herbicide	kg	7.94E+00	Weed control in winter crops 2018 [33]
Lontrel	herbicide	L	4.21E+01	Same as above
Eclipse	herbicide	L	2.02E+02	Same as above
Verdict	herbicide	L	4.91E+01	Same as above
Sulfuric Acid	chemical	kg	6.90E-01	Based on local suppliers
NaOH	chemical	kg	6.50E-01	Efficient costs of new entrant ethanol producers, AECOM Australia. [9]
Canola oil	-	kg	1.84E+00	Based on local suppliers
Corn steep liquor	chemical	kg	3.00E-01	Same as above
Diesel	fuel	L	1.48E+00	Fuel Watch WA [35]
Ethanol delivery to tanker station	transportation	tkm	6.90E-02	Based on AECOM Australia. [9]
2. Activities during grain framing				
Seeding	Contractor job	1 tonne grain	2.10E+01	Department of Primary Industries and Regional Development, WA[31]
Spraying	Contractor job	1 tonne grain	8.83E+00	Same as above
Harvesting	Contractor job	1 tonne grain	1.75E+01	Same as above
Top dressing	Contractor job	1 tonne grain	2.10E+01	Same as above
Salaries	Contractor job	1 tonne grain	3.40E+00	Same as above

Plant and equipment	Contractor job	1 tonne grain	2.80E+00	Same as above
3. Mallee Plantation Establishment				
Initial planning of advisor	Contractor job	gmt**	1.59E-02	Based on Wu et al [28]
Site inspection by advisor	Contractor job	gmt	1.59E-02	Same as above
Site supervision by advisor	Contractor job	gmt	1.59E-02	Same as above
Contract marking out and mapping	Contractor job	gmt	4.77E-02	Same as above
Earthworks by farmer	Contractor job	gmt	3.31E-02	Same as above
Weed control	Contractor job	gmt	3.31E-03	Same as above
Monitoring of Mallee seedling production at nursery	Contractor job	gmt	1.59E-02	Same as above
Transport of seedlings from nursery to site	Contractor job	gmt	8.28E-03	Same as above
Planting	Contractor job	gmt	4.64E-01	Same as above
Monitoring of newly planted seedling	Contractor job	gmt	4.77E-02	Same as above
Spring weed control	Contractor job	gmt	3.31E-03	Same as above
Pesticide	Contractor job	gmt	3.31E-03	Same as above
2^{nd} year weed control	Contractor job	gmt	3.31E-03	Same as above
4. Mallee harvest				
Harvest by farmer	Contractor job	gmt	5.11E+00	Based on Stucley et al [32]
Fertilizer after every harvest	Contractor job	gmt	2.80E-01	Based on Wu et al [28]
Supply chain management	wage	gmt	4.35E+00	Same as above
5. Others				
Land opportunity cost for Mallee plantation	-	gmt	2.18E+01	Based on Stucley et al [32]

* All costs are in AUD 2018

Section D: Sample calculations for improvement strategies

1. Environmental strategy for hydrogen fuel

- Strategy: Renewable electricity (50% wind and 50% solar) for hydrogen production

Item	Base case				After implementing strategies				Reduction from base case
	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	
Electricity per kWh	8.75E-01	1.31E-03	4.39E-06	7.90E+00	1.04E-03	4.95E-06	1.07E-08	1.08E-02	$D_{\text{base case}} - D_{\text{after implementing strategy}}$ GWP=4.79E-01 WC=7.12E-04 LU=2.40E-06 FFD=4.32E+00
Hydrogen production plant impact per VKT (A)	4.79E-01	7.19E-04	2.41E-06	4.34E+00	5.87E-04	3.16E-06	6.01E-09	6.17E-03	
Fuel life cycle (B)	4.95E-01	8.90E-4	2.46E-06	4.57E+00	1.61E-02	1.75E-04	5.45E-08	2.38E-01	
Vehicle materials (C)	6.14E-02	6.03E-4	3.76E-07	7.75E-01	6.14E-02	6.03E-04	3.76E-07	7.75E-01	
Total life cycle impact (D=B+C)	5.57E-01	1.49E-03	2.83E-06	5.34E+00	7.75E-02	7.78E-04	1.64E-07	1.01E+00	
Total life cycle impact of gasoline (E)	2.53E-01	6.19E-04	1.90E-07	2.92E+00	2.53E-01	6.19E-04	1.90E-07	2.92E+00	
Reduction compared to gasoline [(E-D)/E]	-120%	-	-	-83%	69%	-	-	65%	

2. Environmental strategy for EV

- Strategy: Cleaner grid electricity (2030 grid of WA) for EV charging

Item	Base case				After implementing strategy				Reduction from base case
	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	
Electricity per kWh	8.75E-01	1.31E-03	4.39E-06	7.90E+00	5.18E-01	1.25E-03	4.38E-06	5.88E+00	$C_{\text{base case}} - C_{\text{after implementing strategy}}$ GWP=5.30E-02 WC=9.00E-06 LU=0.00E+00 FFD=3.00E-01
Fuel life cycle (A)	1.30E-01	1.94E-04	6.50E-07	1.17E+00	7.67E-02	1.85E-04	6.49E-07	8.71E-01	
Vehicle materials (B)	5.02E-02	2.95E-04	4.19E-07	5.96E-01	5.02E-02	2.95E-04	4.19E-07	5.96E-01	
Total life cycle impact (C=A+B)	1.80E-01	4.90E-04	1.07E-06	1.77E+00	1.27E-01	4.80E-04	1.07E-06	1.47E+00	
Total life cycle impact of gasoline (D)	2.53E-01	6.19E-04	1.90E-07	2.92E+00	2.53E-01	6.19E-04	1.90E-07	2.92E+00	
Reduction compared to gasoline [(E-D)/E]	29%	-	-	39%	50%	-	-	50%	

3. Environmental strategies for PHEV:

- Strategy 1: Use of E10 (10% ethanol and 90% gasoline) in place of gasoline as fuel

Item	Base case				After implementing strategy				Reduction from base case
	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	$C_{\text{base case}}$- $C_{\text{after implementing strategy}}$
Fuel (base case gasoline and E10 is the strategy) for 1 Litre	7.25E-01	7.39E-03	1.45E-06	4.46E+01	7.00E-01	8.69E-03	3.98E-06	4.08E+01	GWP= 8.00E-03 WC= -3.20E-05 LU= -5.70E-08 FFD=7.00E-02
Fuel life cycle (A)	1.79E-01	2.66E-04	3.73E-07	1.61E+00	1.71E-01	2.98E-04	4.30E-07	1.53E+00	
Vehicle materials (B)	3.83E-02	2.69E-04	2.50E-07	3.96E-01	3.83E-02	2.69E-04	2.50E-07	3.96E-01	
Total life cycle impact (C=A+B)	2.17E-01	5.35E-04	6.23E-07	2.00E+00	2.09E-01	5.67E-04	6.80E-07	1.93E+00	
Total life cycle impact of gasoline (D)	2.53E-01	6.19E-04	1.90E-07	2.92E+00	2.53E-01	6.19E-04	1.90E-07	2.92E+00	
Reduction compared to gasoline [(D-C)/D]	14.11%	-	-	31.36%	17.31%	-	-	34%	

- Strategy 1 and 2: Use of E10 in place of gasoline as fuel +Cleaner grid electricity (2030 grid of WA as like EV) for charging

Item	Base case				After implementing strategy				Reduction from base case
	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	
Fuel life cycle (A)	1.79E-01	2.66E-04	3.73E-07	1.61E+00	1.40E-01	2.84E-04	4.29E-07	1.37E+00	$C_{\text{base case}}$- $C_{\text{after implementing strategy}}$
Vehicle materials (B)	3.83E-02	2.69E-04	2.50E-07	3.96E-01	3.83E-02	2.69E-04	2.50E-07	3.96E-01	GWP= 3.90E-02 WC= -1.80E-05 LU= -5.60E-08 FFD=2.30E-01
Total life cycle impact (C=A+B)	2.17E-01	5.35E-04	6.23E-07	2.00E+00	1.78E-01	5.53E-04	6.79E-07	1.77E+00	
Total life cycle impact of gasoline (D)	2.53E-01	6.19E-04	1.90E-07	2.92E+00	2.53E-01	6.19E-04	1.90E-07	2.92E+00	
Reduction compared to gasoline base case [(D-C)/D]	14.11%	-	-	31.36%	30%	-	-	39%	

- Strategy 1, 2 and 3: Cleaner grid electricity for charging + Use of E10 in place of gasoline+ Placement of 180 W_p solar PV on the vehicle

Item	Base case				After implementing strategy				Reduction from base case
	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	$C_{\text{base case}} - C_{\text{after implementing strategy}}$ GWP= 5.20E-02 WC= 8.00E-06 LU= -5.00E-09 FFD=3.50E-01
Fuel life cycle (A)	1.79E-01	2.66E-04	3.73E-07	1.61E+00	1.27E-01	2.58E-04	4.17E-07	1.25E+00	
Vehicle materials (B)	3.83E-02	2.69E-04	2.50E-07	3.96E-01	3.83E-02	2.69E-04	2.50E-07	3.96E-01	
Total life cycle impact (C=A+B)	2.17E-01	5.35E-04	6.23E-07	2.00E+00	1.65E-01	5.27E-04	6.67E-07	1.61E+00	
Total life cycle impact of gasoline (D)	2.53E-01	6.19E-04	1.90E-07	2.92E+00	2.53E-01	6.19E-04	1.90E-07	2.92E+00	
Reduction compared to gasoline base case [(D-C)/D]	14.11%	-	-	31.36%	34.70%	-	-	43.57%	

4. Environmental strategies for E65:

- Strategy: Ethanol blend E55 is considered in place of E65

(i) Environmental impact of different ethanol feedstocks used in the study:

Item	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)
E_{Wheat} , 1L	9.34E-01	1.07E-02	5.29E-04	1.14E+01
E_{Straw} , 1 L	4.60E-01	1.60E-02	2.67E-05	5.93E+00
E_{Mallee} ,1 L	4.65E-01	1.48E-02	3.56E-04	6.16E+00
Gasoline, 1 L	7.25E-01	7.39E-03	1.45E-06	4.46E+01

(ii) Changes in environmental impact due to the switch from E65 to E55

Item	E65				E55			
	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)	GWP ($kgCO_2$)	WC (m^3)	LU (ha.a)	FFD (MJ)
1 L (E65 = 10% E_{Wheat} + 53% E_{Straw} + 2% E_{Mallee} + 35% Gasoline) (E55 = 0% E_{Wheat} + 53% E_{Straw} + 2% E_{Mallee} + 35% Gasoline)	6.00E-01	1.24E-02	7.47E-05	2.00E+01	5.55E-01	1.21E-02	2.20E-05	2.31E+01
Fuel per km with combustion and transportation to retailer (E65 fuel consumption: 0.075 L/km, E55 fuel consumption: 0.072 L/km) (A)	1.30E-01	9.36E-04	5.61E-06	1.51E+00	1.46E-01	8.77E-04	1.58E-06	1.69E+00
Vehicle materials (B)	1.96E-02	1.81E-04	1.09E-07	2.30E-01	1.96E-02	1.81E-04	1.09E-07	2.30E-01
Total (A+B)	1.49E-01	1.12E-03	5.72E-06	1.74E+00	1.66E-01	1.06E-03	1.69E-06	1.93E+00

5. Social strategy in regard to Job creation indicator

- Strategy: Job creation due to local battery production

Based on Boston Energy and Innovation Australia [36] and by considering standard 34.4 working hours per week for Australia [37], 1.50E+07 kWh battery production requires 3.98E+06 direct man-hours (i.e. 15 GWh/year requires 2222.2 direct employment) for Li-ion battery production.

Fuel options	Battery size, kWh (a)	Job creation, man-hours/kWh (b)	Total Job creation, man-hours (c=a*b)	Total km of vehicle [2] (d)	Job creation, man-hours/km for local battery production (e= c/d)
EV	40	3.98E+06 man-hours ÷ 1.50E+07 kWh = 2.65E-01 man-hours/kWh	1.06E+01	1.13E+05	9.42E-05
PHEV	8.8		2.33E+00		2.07E-05
Hydrogen	1.6		4.24E-01		1.84E-10

6. Economic strategies for E55 in regard to LCC indicator

- Strategy 1: Removal of excise rate on ethanol
- Strategy 2: Long term soft loan for the capital cost at the rate of 3% interest rate over the project life
- Strategy 3: 10% of capital (around 19 M AUD) subsidy from the government
- Strategy 3: Removal of GST on E55

Item	Before implementing strategies, AUD/VKT	After implementing strategy 1, AUD/VKT	After implementing strategies 1 and 2, AUD/VKT	After implementing strategies 1, 2 and 3 AUD/VKT	After implementing strategies 1, 2, 3 and 4 AUD/VKT
Cost of E 55 (A)	1.00E-01	9.00E-02	9.00E-02	9.00E-02	8.00E-02
Additional vehicle cost (B)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total life cycle cost (C=A+B)	1.00E-01	9.00E-02	9.00E-02	9.00E-02	8.00E-02
Total cost for gasoline (D)	8.13E-02	8.13E-02	8.13E-02	8.13E-02	8.13E-02
Reduction compared to gasoline [(D-C)]	-2.00E-02	-1.00E-02	-1.00E-02	-1.00E-02	0.00E+00

7. Economic strategies for hydrogen fuel in regard to LCC indicator

<u>Strategies for Fuel</u>

- Strategy 1: With the soft loan scheme and 10% capital subsidy
- Strategy 2: Removal of GST on hydrogen purchase
- Strategy 3: Utilization of product oxygen
- Strategy 4: hydrogen production plant received electricity at a rate of 8.3 cents/kWh through power purchase agreements (PPAs)

Item	Before implementing strategies, AUD/VKT	After implementing strategy 1, AUD/VKT	After implementing strategy 1 and 2, AUD/VKT	After implementing strategy 1, 2 and 3, AUD/VKT	After implementing strategy 1, 2 and 3 and 4, AUD/VKT
Cost of hydrogen fuel (A)	3.07E-01	3.03E-01	2.76E-01	2.64E-01	8.13E-02
Additional vehicle cost (B)	4.81E-01	4.81E-01	4.81E-01	4.81E-01	4.81E-01
Total life cycle cost (C=A+B)	7.87E-01	7.84E-01	7.56E-01	7.44E-01	5.62E-01

Total cost for gasoline (D)	8.13E-02	8.13E-02	8.13E-02	8.13E-02	8.13E-02
Reduction compared to gasoline [(D-C)]	-7.06E-01	-7.03E-01	-6.75E-01	-6.63E-01	-4.81E-01

8. Economic strategies for PHEV in regard to LCC indicator

Strategies for Fuel: No economic strategies for fuel but fuel cost changes due to environmental strategies (i.e.: 6.6% mileage from solar PV)

Alternative fuel Vehicle

- Strategy V1: Removal of GST on vehicle purchase
- Strategy V2: Fifty percent subsidy on vehicle registration
- Strategy V3: Inclusion of import duty on gasoline
- Strategy V4: direct subsidy and/or with the tax benefits

Item	Before implementing strategies, AUD/VKT	After implementing fuel strategies, AUD/VKT	After implementing both fuel and vehicle strategy V1, AUD/VKT	After implementing both fuel and vehicle strategies V1 and V2, AUD/VKT	After implementing both fuel and vehicle strategies V1, V2 and V3, AUD/VKT	After implementing both fuel and vehicle strategies V1, V2, V3 and V4 AUD/VKT
Cost of liquid fuel (base case gasoline) (A)	3.00E-02	2.60E-02	2.60E-02	2.60E-02	2.60E-02	2.60E-02
Cost of electricity (B)	1.30E-02	1.30E-02	1.30E-02	1.30E-02	1.30E-02	1.30E-02
Additional vehicle cost (C)	1.65E-01	1.65E-01	9.90E-02	6.60E-02	5.50E-02	4.10E-02
Total life cycle cost (D=A+B+C)	2.08E-01	2.04E-01	1.38E-01	1.05E-01	9.40E-02	8.00E-02
Total cost for gasoline (E)	8.13E-02	8.13E-02	8.13E-02	8.13E-02	8.13E-02	8.13E-02
Reduction compared to gasoline [(E-D)]	-8.90E-02	-8.70E-02	-5.50E-02	-1.90E-02	-1.00E-02	0.00E+00

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