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GreenAVO: Tracking Australia's progress towards transport decarbonisation

Ying Lu[1,2], Kai Li Lim[1], Jonathan Corcoran[2]

[1]Dow Centre for Sustainable Engineering Innovation, The University of Queensland, Brisbane Qld 4072, Australia

[2]School the Environment, The University of Queensland, Brisbane Qld 4072, Australia

Email for correspondence (presenting author): ying.lu@uq.edu.au

1. Introduction

The urgency of addressing climate change has never been more apparent, with the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) recommending immediate action to decarbonise various sectors of the economy, including transportation. As transport contributes to approximately 18% of carbon emissions globally, the need to reduce these emissions is paramount for human and environmental health (IPCC, 2022, IEA, 2023).Australia's ambitious commitment to achieving net-zero emissions by 2050 has led to increased interest in low or zero emissions vehicles, as well as the country's progress towards transport decarbonisation. To this end, a comprehensive analysis of geography-based vehicle registration and uptake is essential for understanding regional trends and informing future policy decisions.

In recent years, Australia has witnessed a surge in the adoption of electric vehicles (EVs). In 2022, EV sales made up 3% of the market share of new car sales, a relatively low figure compared to other countries that reported a 10% EV market share (EV Volumes, 2022). However, this number has been doubling year-on-year, with most Australians now considering an EV purchase (Electric Vehicle Council, 2021). The federal government's ongoing efforts to develop the first National Electric Vehicle Strategy aim to make EVs more accessible by implementing tax exemptions, introducing more affordable models, and expanding the limited charging network. As a result, it is projected that by 2030, 3.8 million electric vehicles will be on Australian roads (Department of Industry, 2021).

Comparatively, as of 31 January 2022 (Australian Government, 2022), there were 20.7 million registered motor vehicles in Australia, representing a 2% increase from January 2021. This growth was seen across all states and territories, with the largest proportional increases being seen in Tasmania, Queensland and Western Australia, with 2.9%, 2.7% and 2.5% respectively. The states of New South Wales, Victoria and Queensland have the largest number of vehicle registrations, making up over 76% of the total registered vehicles. It's also worth mentioning that while petrol-powered vehicles still comprise the majority of the fleet at 70.1%, this number has decreased from 71.3% in 2021. Meanwhile, diesel-powered vehicles saw an increase to 27.2% in 2022, up from 26.4% in 2021. The report also highlights the growing trend of electric vehicles, with 40,000 registered battery electric vehicles (BEV) and 277,000 registered hybrid-electric vehicles (HEV) as of 31 January 2022. This represents a 100% increase in BEV registrations and a 35% increase in HEV registrations from 2021.

Coupled with the increasing adoption of EVs, Australia's state energy commitments to transition to renewables further underscore the importance of tracking the country's progress towards transport decarbonisation. A geographically orientated analysis of vehicle registration and uptake will provide important insights into regional disparities alongside opportunities for improvement, ultimately supporting Australia's goal of reaching net-zero emissions by 2050. As the nation continues to pursue its environmental objectives, a data-driven approach to understanding the adoption and impact of low or zero-emissions vehicles will be crucial for guiding policy decisions and shaping a more sustainable future. Our work intends to propose an empirical solution to this knowledge gap through the GreenAVO Project.

This paper uses insights from the GreenAVO Project to present contributions across the following topics: (1) to explore the variation of annual passenger vehicle CO_2 emissions and fuel consumption across Australian regions, and (2) to examine the extent to which the total number of vehicles and geolocations affect their CO_2 emissions and fuel consumption.

2. The GreenAVO Project

The GreenAVO (The Green Australian Vehicle Ownership Database) project, led by The University of Queensland, aims to augment, and extend the Australian Urban Research Infrastructure Network (AURIN)'s 2014 cross-sectional database of vehicle ownership and environmental efficiency. The project will achieve this by automating data extraction from government APIs, archiving new data for longitudinal trend observation, and expanding existing AURIN coverage to postcodes throughout all Australian states and territories for observing socio-spatial patterns.

GreenAVO enables the mapping, modelling, and monitoring of vehicle ownership by vehicle make and model, energy consumption, emissions, and infrastructure requirements. This evidence base will facilitate the development of infrastructure responsive to emerging vehicle technologies, such as fuel-efficient, hybrid, electric, and eventually autonomous vehicles. GreenAVO also supports evidence-based policy for accelerating the transition towards environmentally sustainable mobility, strengthening national energy security, efficient and resilient energy distribution and storage, and aligning with international climate goals like the Paris Agreement.

Alignment with national research priorities such as transport, energy, and environmental change highlights the potential impact of GreenAVO beyond the project lifecycle. For the transport national research priority, GreenAVO provides up-to-date trends and spatial patterns in Australian vehicle ownership, energy consumption, emissions, and infrastructure demands, enabling insights into the uptake of hybrid and electric vehicles and associated impacts. For the energy national research priority, GreenAVO will help identify opportunities for powering Australian transport with clean, renewable energy sources, integrating and distributing transport energy via the energy grid, and storing and distributing energy via electric vehicles. Finally, for the environmental change national research priority, GreenAVO will improve accuracy and precision when measuring and predicting environmental damage caused by transport, supporting evidence-based policymaking for sustainable conservation, transport, and land use.

This paper uses the GreenAVO dataset that is consolidated through sources from the Australian Government's Department of Infrastructure, Transport, Regional Development, Communications and the Arts. First from the Bureau of Infrastructure and Transport Research Economics (BITRE) (Australian Government, 2022), and second from the Green Vehicle Guide (GVG) (Australian Government, 2023). The data is current as of January 2023. BITRE provides the vehicle registration information while the GVG enables the analysis on vehicle CO_2 emissions and fuel consumption, with results and their associated methodologies presented in Section 3.

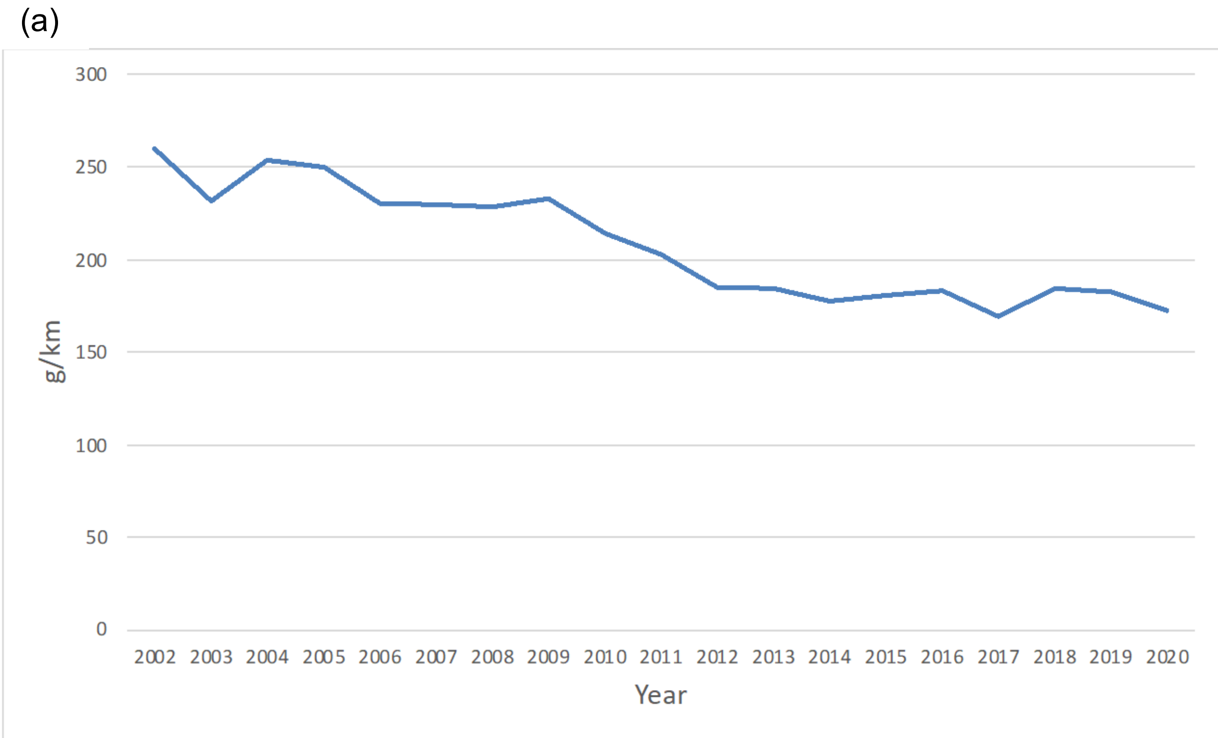
3. Results

In this section, we present our preliminary findings on the maximum potential for transport emissions resulting from vehicle uptake at a spatial level, using both a comprehensive descriptive analysis and a panel regression model.

3.1. Descriptive analysis

CO_2 emissions and fuel consumption per car are plotted by year (from 2002 to 2020) to capture their temporal patterns (Figure 1 (a, b)). These figures show the temporal patterns of CO_2 emissions and fuel consumption per car in each year. Both CO_2 emissions and fuel consumption exhibit a decreasing trend overall. There is a pronounced decreasing wave from 2009 to 2012 regarding both CO_2 emissions and fuel consumption. Following a slight increase from 2017 to 2018, CO_2 emissions and fuel consumption began to decline again. A correlation test confirms that CO_2 emissions and fuel consumption are positively correlated (0.999).

Figure 1: (a) CO_2 emissions, and (b) fuel consumption per car per year (2002-2020)



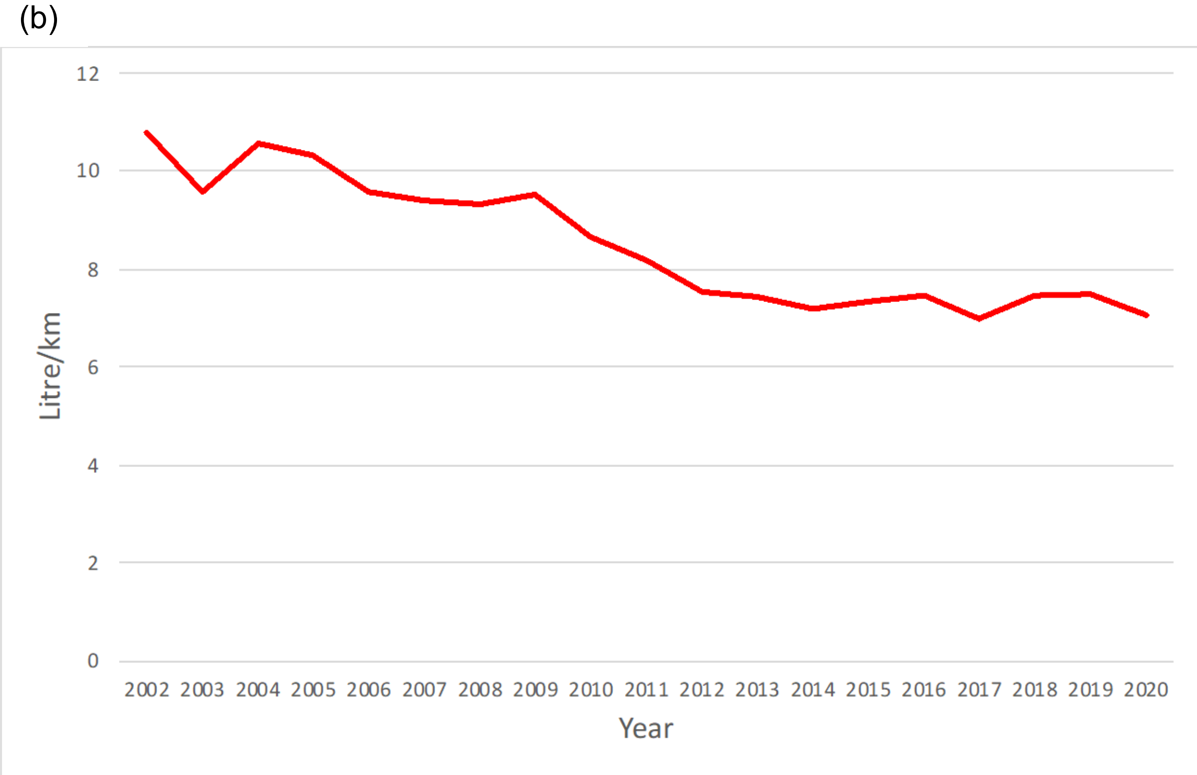


Figure 2 (a, b) allow a comparison of the trends in car CO_2 emissions and fuel consumption between capital cities and suburban areas. Warmer colours, such as red, indicate higher levels of emissions and fuel consumption. Typically, suburban areas display higher levels of emissions and fuel consumption than the eight capital cities. Notably, the Rest of Northern Territory and Rest of Western Australia regions show emissions and fuel consumption levels that are relatively higher than other GCCSAs. Although CO_2 emissions and fuel consumption values have decreased from 2012 to 2020, values in Rest of Northern Territory and Rest of Western Australia maintain a comparatively high level.

Figure 2: (a, top) Heat map of CO_2 emissions, and (b, bottom) fuel consumption per car across GCCSAs.

Year	Greater Sydney	Rest of NSW	Greater Melbourne	Rest of VIC	Greater Brisbane	Rest of QLD	Greater Adelaide	Rest of SA	Greater Perth	Rest of WA	Greater Hobart	Rest of TAS	Greater Darwin	Rest of NT	Canberra
2002	249.47	265.67	257.08	272.65	255.24	261.61	256.80	279.12	258.73	272.19	254.67	259.54	262.51	281.34	252.41
2003	222.62	236.91	226.46	242.09	227.37	239.01	228.42	247.17	233.72	260.84	227.36	234.95	243.79	258.10	225.14
2004	246.83	258.45	251.76	263.60	250.64	255.25	252.44	267.52	252.90	263.14	246.42	252.64	253.97	258.88	248.57
2005	244.08	253.12	248.72	260.12	246.17	249.99	249.91	262.37	251.10	258.66	247.07	253.12	250.90	260.08	245.07
2006	226.88	231.19	230.21	236.73	227.23	229.45	231.22	238.41	231.19	235.98	227.15	230.36	230.30	236.85	226.29
2007	229.98	230.07	228.08	228.96	230.20	232.75	230.56	231.58	231.63	236.32	222.60	227.68	238.40	246.96	224.78
2008	228.64	228.21	228.34	229.71	227.09	227.66	229.58	233.88	229.69	229.11	221.41	224.24	229.13	229.51	225.64
2009	231.04	233.72	233.14	237.93	230.41	231.50	232.70	238.73	234.70	235.80	229.00	231.02	232.63	237.92	227.76
2010	213.28	214.22	214.70	217.41	211.89	212.48	214.95	218.55	215.70	216.37	209.28	211.01	214.48	218.00	209.85
2011	201.50	204.47	198.97	204.49	199.81	205.25	200.79	207.81	204.71	216.63	200.31	206.06	216.99	221.09	194.80
2012	179.15	189.63	179.53	190.75	184.50	192.91	182.60	198.81	185.43	205.43	182.26	188.31	191.33	203.59	178.12
2013	181.58	188.99	179.33	188.10	184.11	187.44	182.98	192.99	185.75	193.05	186.51	191.63	188.03	188.84	180.06
2014	173.59	183.68	171.75	182.57	176.66	181.72	178.13	190.91	177.16	189.79	177.87	183.57	185.40	187.63	169.94
2015	174.44	186.47	175.32	188.06	179.44	186.09	180.94	195.20	182.65	198.64	182.55	186.96	193.42	202.82	170.76
2016	177.36	190.45	176.70	188.39	183.98	192.19	181.49	197.69	185.46	205.78	180.90	185.56	200.22	207.83	175.71
2017	166.47	174.53	166.36	175.20	168.67	171.70	169.40	176.45	170.34	177.09	171.35	176.91	170.50	175.27	166.11
2018	181.78	187.42	180.29	186.09	185.59	188.13	183.86	189.93	186.20	192.81	182.60	184.33	192.95	196.39	177.15
2019	178.75	186.33	179.13	186.88	183.02	188.67	182.95	193.07	184.56	195.54	178.53	185.06	192.63	197.70	168.34
2020	169.26	177.01	169.10	176.39	172.50	177.58	169.28	182.21	175.87	186.34	174.72	177.88	183.02	184.02	158.91

Year	Greater Sydney	Rest of NSW	Greater Melbourne	Rest of VIC	Greater Brisbane	Rest of QLD	Greater Adelaide	Rest of SA	Greater Perth	Rest of WA	Greater Hobart	Rest of TAS	Greater Darwin	Rest of NT	Canberra
2002	10.42	11.02	10.71	11.30	10.61	10.83	10.71	11.57	10.76	11.20	10.53	10.71	10.86	11.70	10.57
2003	9.31	9.72	9.45	9.91	9.41	9.75	9.48	9.99	9.66	10.43	9.38	9.61	9.86	10.29	9.41
2004	10.31	10.72	10.56	10.99	10.42	10.54	10.53	11.07	10.56	10.83	10.23	10.41	10.50	10.67	10.39
2005	10.14	10.40	10.36	10.73	10.15	10.24	10.34	10.69	10.38	10.49	10.14	10.37	10.17	10.52	10.19
2006	9.54	9.54	9.67	9.76	9.44	9.41	9.67	9.74	9.61	9.56	9.36	9.43	9.34	9.62	9.54
2007	9.52	9.32	9.41	9.25	9.36	9.35	9.46	9.26	9.47	9.37	9.05	9.19	9.57	9.80	9.29
2008	9.43	9.24	9.42	9.34	9.23	9.16	9.44	9.42	9.38	9.13	8.99	9.05	9.17	9.17	9.30
2009	9.54	9.47	9.63	9.67	9.38	9.33	9.61	9.61	9.60	9.41	9.30	9.31	9.33	9.51	9.38
2010	8.70	8.58	8.77	8.74	8.53	8.48	8.75	8.73	8.74	8.55	8.42	8.44	8.52	8.62	8.56
2011	8.26	8.15	8.13	8.15	8.02	8.15	8.17	8.21	8.26	8.49	8.06	8.21	8.62	8.69	7.93
2012	7.41	7.62	7.39	7.63	7.50	7.73	7.49	7.88	7.56	8.07	7.43	7.57	7.72	8.08	7.33
2013	7.43	7.53	7.32	7.48	7.40	7.45	7.44	7.63	7.50	7.57	7.49	7.65	7.44	7.39	7.35
2014	7.14	7.36	7.03	7.30	7.14	7.28	7.26	7.55	7.19	7.48	7.19	7.36	7.41	7.46	6.97
2015	7.18	7.49	7.22	7.57	7.29	7.47	7.43	7.77	7.42	7.81	7.39	7.53	7.70	7.95	7.04
2016	7.31	7.64	7.26	7.55	7.46	7.70	7.44	7.83	7.51	8.09	7.36	7.49	8.00	8.23	7.25
2017	6.94	7.09	6.92	7.10	6.92	6.98	7.03	7.10	7.03	7.11	7.07	7.19	7.03	7.18	6.93
2018	7.42	7.49	7.38	7.47	7.47	7.53	7.47	7.53	7.51	7.57	7.42	7.40	7.61	7.67	7.30
2019	7.41	7.56	7.42	7.60	7.48	7.63	7.48	7.73	7.53	7.79	7.35	7.53	7.66	7.79	7.03
2020	7.04	7.14	7.05	7.14	7.02	7.16	6.93	7.25	7.12	7.36	7.12	7.18	7.27	7.26	6.64

3.2. Panel regression analysis

A panel regression model is employed to determine the extent to which internal combustion engine vehicles (ICEs) and EVs impact CO_2 emissions and fuel consumption. The equations are:

$$\ln(C_{it}) = \beta_0 + \beta_{vehicle}\ln(ICE_{it}) + \beta_{EV}\ln(EV_{it}) + \beta_{2003}Y_{2003} + \beta_{2004}Y_{2004} + \beta_{2005}Y_{2005} + \beta_{2006}Y_{2006} + \beta_{2007}Y_{2007} + \beta_{2008}Y_{2008} + \beta_{2009}Y_{2009} + \beta_{2010}Y_{2010} + \beta_{2011}Y_{2011} + \beta_{2012}Y_{2012} + \beta_{2013}Y_{2013} + \beta_{2014}Y_{2014} + \beta_{2015}Y_{2015} + \beta_{2016}Y_{2016} + \beta_{2017}Y_{2017} + \beta_{2018}Y_{2018} + \beta_{2019}Y_{2019} + \beta_{2020}Y_{2020} + \beta_{RNSW}RNSW_i + \beta_{GM}GM_i + \beta_{RV}RV_i + \beta_{GB}GB_i + \beta_{RQLD}RQLD_i + \beta_{GA}GA_i + \beta_{RSA}RSA_i + \beta_{GP}GP_i + \beta_{RWA}RWA_i + \beta_{GH}GH_i + \beta_{RT}RT_i + \beta_{GD}GD_i + \beta_{RNT}RNT_i + \beta_{CAN}CAN_i + \beta_{other}Other_i + V_i + \varepsilon_{it} \qquad (1)$$

$$\ln(F_{it}) = \beta_0 + \beta_{vehicle}\ln(ICE_{it}) + \beta_{EV}\ln(EV_{it}) + \beta_{2003}Y_{2003} + \beta_{2004}Y_{2004} + \beta_{2005}Y_{2005} + \beta_{2006}Y_{2006} + \beta_{2007}Y_{2007} + \beta_{2008}Y_{2008} + \beta_{2009}Y_{2009} + \beta_{2010}Y_{2010} + \beta_{2011}Y_{2011} + \beta_{2012}Y_{2012} + \beta_{2013}Y_{2013} + \beta_{2014}Y_{2014} + \beta_{2015}Y_{2015} + \beta_{2016}Y_{2016} + \beta_{2017}Y_{2017} + \beta_{2018}Y_{2018} + \beta_{2019}Y_{2019} + \beta_{2020}Y_{2020} + \beta_{RNSW}RNSW_i + \beta_{GM}GM_i + \beta_{RV}RV_i + \beta_{GB}GB_i + \beta_{RQLD}RQLD_i + \beta_{GA}GA_i + \beta_{RSA}RSA_i + \beta_{GP}GP_i + \beta_{RWA}RWA_i + \beta_{GH}GH_i + \beta_{RT}RT_i + \beta_{GD}GD_i + \beta_{RNT}RNT_i + \beta_{CAN}CAN_i + \beta_{other}Other_i + V_i + \varepsilon_{it} \qquad (2)$$

where C_{it} and F_{it} denote the total CO_2 emissions and fuel consumption respectively on postcode i in period t, The vector $\beta_{vehicle}$ and β_{EV} are the total number of internal combustion engine vehicles (ICEs) and EVs respectively on postcode i in period t, Y_{2003}~Y_{2020} are year dummy variables, and β_{RNSW}~β_{other} represent dummy variables indicating if postcode i falls within these Greater Capital City Statistical Areas (GCCSAs).

The model adopts a log-linear form for the total number of ICEs and EVs. This form implies that the coefficients linked to these two variables signify their elasticity, allowing interpretation of the coefficients as percentage changes in CO_2 emissions and fuel consumption.

To comprehend the influence of vehicle numbers, years and geographic locations on CO_2 emissions and fuel consumption, we employed a panel regression analysis. Table 1 presents the estimated results of the panel regression models. Coefficients for total of CO_2 emissions were determined using both random effects and fixed effects estimators. Similarly, coefficients for total fuel consumption were estimated using both models. The Hausman test statistics were significant for both CO_2 emissions and fuel consumption models, suggesting the fixed effects estimator is preferable. We present results for both models to provide robustness checks.

Vehicle numbers showed a positive association with CO_2 emissions and fuel consumption in both models, indicating rising CO_2 emissions with an increasing number of vehicles. Specifically, coefficients for total of CO_2 emissions were 1.001 and 0.992 in the fixed and random effects models, respectively. Coefficients for fuel consumption were 1.035 and 1.064 in the corresponding models. Thus, a 1% uptick in ICEs correlates with roughly 1.035%–1.064% rise in CO_2 emissions and about a 1.034%–1.057% increase in fuel consumption. The number of EVs (BEVs and HEVs) was inversely related to CO_2 emissions in both models, suggesting a 1% growth in EVs corresponds to a 0.017% drop in CO_2 emissions. Similarly, a 1% rise in EVs results in approximately a 0.013% reduction in fuel consumption.

Year dummy variable coefficients displayed an annual reduction in CO_2 emissions and fuel consumption. As per the coefficients for each Greater Capital City Statistical Area (GCCSA), most regions saw higher CO_2 emissions and fuel consumption than Greater Sydney, save for Greater Melbourne and Greater Adelaide, where coefficients were not statistically significant. Wu et al. (2021) determined that job accessibility via public transit in Sydney surpassed other Australian capital cities. This suggests that Greater Sydney's public transport is more efficient, leading to lower private vehicle use and consequently, reduced CO_2 emissions and fuel consumption.

Table 1: The estimation results for mean CO_2 emissions and fuel consumption

Variables	**CO_2 emissions**		**Fuel consumption**	
	Random effects	Fixed effects	Random effects	Fixed effects
Constant		5.339***		2.186***
ln(ICE)	1.064***	1.035***	1.057***	1.034***
ln(Number of EVs)	-0.017***	-0.017***	-0.012***	-0.013***
Year 2003	-0.105***	-0.082***	-0.116***	-0.098***
Year 2004	-0.052***	-0.020***	-0.048***	-0.022***
Year 2005	-0.064***	-0.034***	-0.071***	-0.047***
Year 2006	-0.164***	-0.124***	-0.167***	-0.135***
Year 2007	-0.165***	-0.130***	-0.189***	-0.161***
Year 2008	-0.189***	-0.144***	-0.207***	-0.172***
Year 2009	-0.162***	-0.121***	-0.180***	-0.148***
Year 2010	-0.251***	-0.209***	-0.280***	-0.245***
Year 2011	-0.276***	-0.242***	-0.309***	-0.281***
Year 2012	-0.354***	-0.311***	-0.380***	-0.346***
Year 2013	-0.391***	-0.343***	-0.423***	-0.384***
Year 2014	-0.398***	-0.361***	-0.427***	-0.396***
Year 2015	-0.391***	-0.336***	-0.416***	-0.372***
Year 2016	-0.360***	-0.312***	-0.387***	-0.348***
Year 2017	-0.465***	-0.417***	-0.477***	-0.438***
Year 2018	-0.388***	-0.340***	-0.416***	-0.378***
Year 2019	-0.360***	-0.321***	-0.378***	-0.346***
Year 2020	-0.408***	-0.373***	-0.431***	-0.403***
Rest of New South Wales		0.063***		0.036***
Greater Melbourne		0.012***		0.009***
Rest of Victoria		0.064***		0.038***
Greater Brisbane		0.018***		0.002
Rest of Queensland		0.070***		0.036***
Greater Adelaide		0.031***		0.023***
Rest of South Australia		0.074***		0.043***
Greater Perth		0.033***		0.018***
Rest of Western Australia		0.079***		0.043***

Greater Hobart		0.018***		0.003
Rest of Tasmania		0.036***		0.018***
Greater Darwin		0.071***		0.041***
Rest of North Territory		0.091***		0.056***
Canberra		-0.009		-0.010
Other		-0.126**		-0.129**
Number of groups	2,634	2,634	2,634	2,634
Number of observations	47,760	47,760	47,760	47,760
Hausman test	443.54****		3513.2***	
R-squared	0.976	0.991	0.980	0.994

Note: *** Significant at 99% level. **Significant at 95% level. *Significant at 90% level.

4. Conclusion

This paper presented a detailed geographically orientated analysis of vehicle registration across Australia, with a particular focus on EVs and understanding their contribution towards achieving the national net-zero emission targets by 2050. Through the GreenAVO project, we aimed to provide new and important insights into regional disparities and highlight the opportunities that exist for improvement in relation to supporting Australia's goal of reaching net-zero emissions by 2050. Our preliminary results presented here showed a general decreasing trend in both CO_2 emissions and fuel consumption, with CO_2 emissions positively correlated with the number of vehicles on the road. Importantly, our findings indicated that the increasing adoption of EVs has imposed a significant role in mitigating transport-related emissions.

The GreenAVO project will continue to expand its coverage, enabling researchers to map, model, and monitor vehicle ownership by make, model, energy consumption, emissions, and infrastructure requirements. By providing high-quality, up-to-date, and spatiotemporal data, GreenAVO minimises start-up burdens for individual research projects and offers fast and efficient insights into temporal trends and spatial patterns across various aspects of private vehicle ownership in Australia. This new evidence base will facilitate the development of infrastructure responsive to emerging vehicle technologies and support evidence-based policy for accelerating the transition towards environmentally sustainable mobility, thereby contributing to national research priorities such as transport, energy, and environmental change.

As Australia continues to pursue its environmental objectives, the GreenAVO project and its data-driven approach offer a valuable resource for understanding the adoption and impact of low or zero-emission vehicles. By guiding policy decisions and shaping a more sustainable future, the project will play a crucial role in helping Australia achieve its ambitious emissions target.

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