CO_2 emissions of Australian and European Sport Utility Vehicles[1]

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Introduction

To address the increasing emissions from road transport and mitigate climate change, in 2009 the first CO_2 standards were adopted in European Union (EU), setting intermediate fleet-wide targets for the next decade – 130 g/km for 2015, and 95 g/km for 2020 – and providing time for the technology to mature and the car fleets to adapt (Regulation (EC) No 443/2009). Multiple studies indicated an increasing discrepancy between the officially reported CO_2 values and the ones realised under real-world (RW), reaching in 2017 a gap of 40% (Pavlovic et al., 2020; Tietge, 2019). The main reason was the flexible definition of the certification procedure used for efficiency benchmarking, the New European Driving Cycle (NEDC). Consequently, the NEDC-based CO_2 and fuel consumption values continuously decreased, but without improvement in RW conditions. They undermined the efforts to produce cleaner vehicles and reduce the CO_2 footprint of road transport. The EU regulators' reaction was to introduce a new certification procedure, the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) to address the RW gap issue and to provide more detail in the manufacturers' CO_2 and fuel consumption data. The new test protocol corresponded better to RW conditions resulting to a substantial drop of the gap – to half – between certified and the RW values (Fontaras et al., 2017; Pavlovic et al., 2020; TER, 2019). In 2019, new regulations integrated the new protocol and created a path for CO_2 standards in the following decade, also putting in place provisions to ensure the CO_2 gap is not growing again (Regulation (EU) 2019/631).

The evolution of EU regulation increased confidence in the stability of the CO_2 framework, which aligned with a larger climate ambition in the EU (European Commission, 2019). In 2023 the EU voted for more ambitious CO_2 targets for 2030 and a reduction of 100% for 2035 (Regulation (EU) 2023/851). These actions intend to bring public attention and progressively decarbonise the sector. It is already visible that vehicle electrification is rapidly increasing, providing a cleaner and more efficient on-road fleet. However, this is not the case worldwide, even among developed countries. In Australia (AU) light-duty vehicles are still being certified using the NEDC, and the growth of the sales of electric vehicles is limited compared to EU (TER, 2019). Lacking CO_2 emissions standards, in parallel to continuous growth in the sales of heavier and more energy-consuming sport-utility vehicles (SUV) and utes, vehicle manufacturers have no incentive to introduce fuel-efficient vehicles into the AU fleet. Moreover, the vehicles are less fuel efficient than identical makes and models available overseas (Smit et al., 2022, 2021). As a result, the AU passenger vehicle fleet is moving towards higher absolute CO_2 emissions and a likely widening RW CO_2 gap. A recent study showed that the AU on-road fleet will only achieve a 35-45% reduction in (well-to-wheel) GHG emissions in road transport in 2050 compared to 2019 levels, even if a delayed and ambitious EU EV penetration scenario is followed (Smit, 2023).

The present paper shows the preliminary results of the simulations performed to analyse SUVs' RW consumption and CO_2 gap and provides insights by comparing a regulated (EU) versus a relatively non-regulated market (AU). The EU is the reference market where CO_2 targets have been established for over a decade and where up-to-date test procedures have been adopted, while the Australian market provides the unregulated example with the continued use of an outdated test protocol and a lack of (mandatory) CO_2 or fuel efficiency regulation.

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Methodology

Overview. A schematic representation of the approach followed to simulate the annual CO_2 gap of the SUV fleet for EU and AU is shown in Figure 1. Technical characteristics of indicative SUVs from both regions were collected and combined with representative RW trips and representative ambient temperatures to build realistic RW scenarios. Combinations of all the different parameters, i.e., representative vehicles, trips, and temperatures, were simulated with a vehicle simulator to derive each individual vehicle's RW CO_2 gap from the certified values. For the present research, the study team has used the PyCSIS tool that is a light version of CO_2MPAS (Fontaras et al., 2018). PyCSIS performs detailed simulations because its physical models are sensitive to the individual vehicle characteristics and the environmental parameters used as inputs. It has proven its accuracy in simulating laboratory tests (following both NEDC and WLTP certifications) and RW driving in several studies, with the most recent assessing the EU fleet gap of 2018 and 2019 (Komnos et al., 2022).To derive the SUV fleet annual RW consumption and gap, the individual vehicle RW gaps simulated were then intersected with the below distributions:

1. Certified CO_2 distributions of SUVs of one registration year for both EU and AU.
2. RW trip distance distributions of annual usage.
3. Population-weighted average ambient temperature distributions.

For each of these distributions, 10,000 Monte Carlo simulations were performed following their characteristic shapes. Then, each Monte Carlo simulation was compared to the values previously selected as representatives. This procedure was followed to assign a percentage correspondence to the full distribution. For example, each vehicle selected reflects a specific percentage of vehicles in the fleet in CO_2 terms. For this purpose, the distance between each representative value and each Monte Carlo simulated value was calculated; then, every value of the 10,000 Monte Carlo is distributed to the representative value that their distance is the minimum.

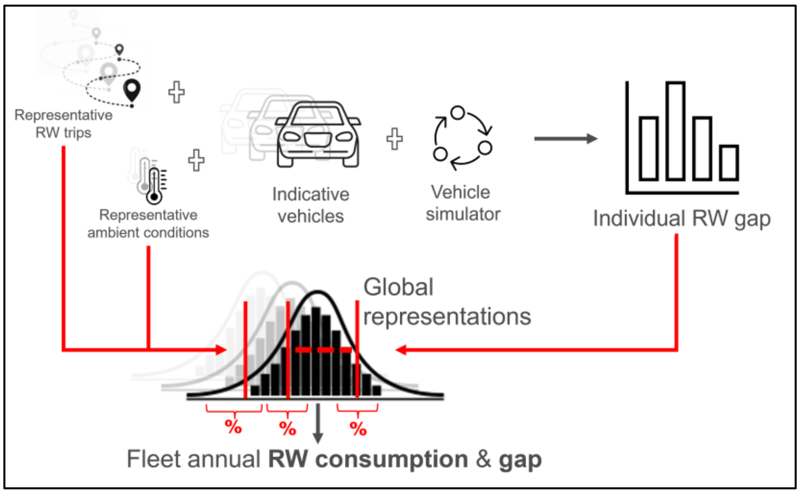

Figure 1: Schematic workflow of the process followed.

The following subparagraphs provide detailed explanations for distributions and the representative values used for the simulations.

EU and AU and representative SUVs and fleets. Finding representative EU and AU market data for SUVs was a crucial step. For the EU market, the Joint Research Centre (JRC) database that collects the vehicle technical characteristics of the vehicles tested each year for the EU Market Surveillance (Bonnel et al., 2022) was used, and four indicative vehicles were selected. Four SUVs tested under real-world conditions (PEMS) and representative of typical SUVs sold in AU (Smit et al., 2022) were selected for AU. In Table 1, essential characteristics for both vehicle sets are provided. Each set of vehicles is ordered by their certified CO_2 value. The AU vehicles are a mix of diesel and gasoline vehicles and have larger engine capacities and higher weights as compared with the EU SUVs. Altogether, the first indication is that the AU SUVs are bigger vehicles than the ones most frequently sold in EU. Regarding the SUV fleets of both regions, it was decided to study the registered vehicles in the year 2020. The 2020 EU registered SUVs were collected by combining the 2020 EU monitoring dataset for passenger vehicles reported by the European Environment Agency (European Environment Agency, 2023), with a database created by collecting data from online sources. This provided new vehicle sales numbers by make and model and with associated NEDC and WLTP-certified CO_2 values. The dataset was used to identify which vehicles are SUVs. In the EU 3,192,369 vehicles were identified as new SUVs sold in 2020.

Table 1: Characteristics of the sampled EU and AU representative SUVs. Gas: Gasoline; Dies: Diesel; T: Turbo engine; A: Naturally aspirated engine.

	EU				AU			
	Veh 1	Veh 2	Veh 3	Veh 4	Veh 1	Veh 2	Veh 3	Veh 4
Fuel	Gas T	Dies T	Gas T	Gas T	Gas N	Dies T	Dies T	Gas N
Gear box	Auto	Auto	Auto	Auto	Auto	Auto	Auto	Auto
Engine capacity	1.2	2.0	1.4	2.0	2.5	3.0	2.8	3.5
Rated power	96	110	110	141	126	130	130	218
Vehicle mass	1208	1728	1592	1645	1560	2142	2315	2045
Year	2021	2021	2017	2019	2020	2018	2019	2019

The AU Green Vehicle Guide (DITRDCA, 2020) was used collect the NEDC certified CO_2 values of all the SUVs present in the AU market for the period 2018-2021. AU sales data were retrieved from online sources for the 100 top sold vehicles in 2020. Combining the two sources 376,655 vehicles were identified as new SUVs in 2020 for AU, which is about 80% of total SUV sales in 2020 (TER, 2022). Figure 2 shows the CO_2 distributions for both regions and the two sets of representative vehicles. Distributions were produced by fitting the fleet data to lognormal and gamma distributions for EU and AU CO_2 values, respectively. The selected probability distributions for each fleet provided the best fit and lowest errors.

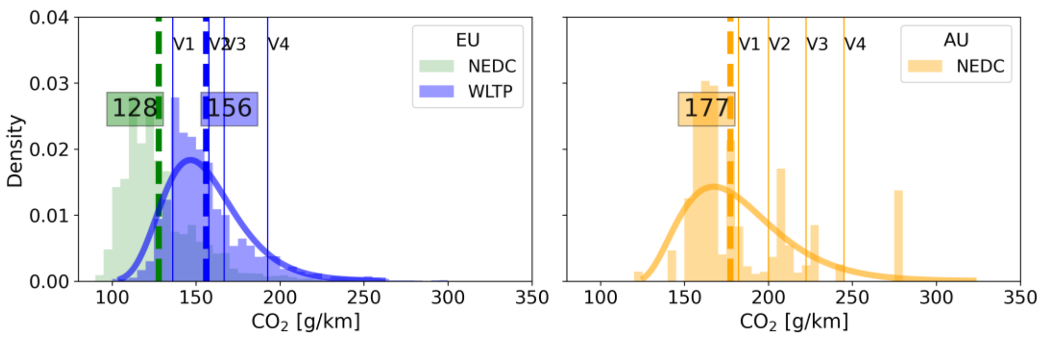

Figure 2: CO_2 certified values for EU (left) and for AU (right). The vertical lines indicate the certified CO_2 values of the representative vehicle selected. The thick lines correspond to the distributions fitted to the data.

In the Figure 2 (left), two distributions appear for the new EU SUVs because 2020 was the last year that regulation allowed for a smooth transition from NEDC to WLTP. Comparing the EU with the AU distributions and their average values (Figure 2), it is evident that even with the more representative protocol of WLTP, the EU SUV fleet is, on average, more efficient by 21 g/km of CO_2. The accuracy of the EU distributions is considered acceptable since they were produced using official information reported by the EU member states. This is not the case for the AU distributions. However, comparison with a detailed study of the 2018 AU sales and emissions data (TER, 2019) confirms good agreement and provides confidence in the initial results for AU.

Real-world set up. Previous studies (Fontaras et al., 2017) split the factors in vehicle-related factors, environmental factors and traffic/driving pattern related factors. Vehicle-related factors are reflected in the vehicle characteristics of the representative vehicles selected for the study. The impact of the road factors is introduced by utilising trips recorded in a one-year RW campaign (Pavlovic et al., 2020). To reduce the computational cost of the simulations, representative trips falling to similar average trip speeds as in the 4 phases of the WLTP cycle (Low – D1, Medium - D2, High – D3, Extra-High – D4) were selected. For the Extra-High phase, two different speed profiles were used to understand the influence of the highway trips in the fuel consumption and the total annual milage driven (D4 case 1 and case 2). More details are shown in Table 2. For this initial investigation, it has been assumed that RW driving conditions are comparable in the EU and AU, but future work will include AU driving behaviour in more detail.

Table 2: Distances of the trips selected for the simulations.

	D1	D2	D3	D4 case 1	D4 case 2
RW distances [km]	3	10	27	130	216

Annual average ambient temperatures were collected for all EU Member States and states and territories in AU via web scraping and combined with population figures. This showed that the two regions have different range of ambient temperatures that can impact the RW vehicle usage (e.g., need for heating, ventilation and air conditioning of the cabin), the vehicle efficiency (e.g., cold-start). To understand the variability, in addition to of the population-weighted mean, also the temperatures corresponding to the 1st, 25th, 75th, and 99th percentiles of the distributions were simulated (hereafter referred to temperatures T1 to T5): 3°C (T1), 8°C (T2), 10.5°C (T3), 14°C (T4) and 17°C (T5) for EU, and 11°C (T1), 14°C (T2), 17°C (T3), 19°C (T4) and 22°C (T5) for AU. Besides the population weighted mean, another way to produce representative ambient temperatures is by applying vehicle-kilometres-travelled (VKT) weight average. Comparing the two methods we see that the population-weighted mean calculated for AU (17°C) is close to the VKT weighted temperature estimated in previous study, that was 18.2°C (Smit, 2014).

Results

Model validation. PyCSIS has been validated under different vehicle configurations and simulation environments, but validation was performed also for the indicative vehicles used for the present study. The validation included an assessment if the selected vehicles' certified values are reproduced and if their RW performance is replicated in the case of the AU representative vehicles. It should be noted the simulation of the certified values followed the respective test cycles, the initial vehicle conditions (e.g., initial engine temperatures) and test cell temperature. For the EU vehicles the official test mass and road load coefficients were used. For the AU vehicles, road load coefficients were obtained from coast-down tests (Smit et al., 2022) and were assumed to be WLTP representative. The translation to NEDC representative values followed the EU NEDC-WLTP correlation work (Regulation (EU) 2017/1153). Regarding the AU RW trips used for the validation, the PyCSIS simulated CO_2 signals and aggregated values were compared to measured emissions during on-road trips performed in Sydney using portable emissions measurement systems. Table 3 shows that all the simulated cases show acceptable accuracy, giving confidence for the next steps.

Table 3: Sampled vehicle validation.

		Veh 1	Veh 2	Veh 3	Veh 4	Average
Error [%]	AU certification (NEDC)	-3.1	-3.8	4.9	15.6	3.4
	AU RW trips	1.9	6.1	1.3	0.5	2.5
	EU certification (WLTP)	2.4	8.2	6.1	4.1	5.2

Global representations and CO_2 gap. In this subparagraph using the global representations from the distributions derived from the SUV fleets, the annual trip distances, and average ambient temperatures, the previous results will be expanded to produce annual SUV fleet values. The fleet shares in Table 4 provide the share of each individual vehicle in the fleet. The shares sum up to the total number of SUVs registered in the two regions in 2020. The trip shares sum up to 10,671 km for case 1 and 11,770 km for case 2, with the half of them driven in the highway (trips D4). Regarding the temperatures selected, only the extremes appear to have lower contribution than the others. In further work, EU trip data will be compared with AU trip data to further refine these initial estimates. To understand the possible influence of the vehicle to the CO_2 gap, Figure 3 shows the annual RW gap simulated for the four EU and four AU SUVs. The average annual CO_2 gap in EU (WLTP-based) ranges between 7 and 19%, showing a declining trend as SUV are getting bigger. Similar trends appear for AU when the estimated WLTP-based CO_2 values are examined. The NEDC-based gap is considerably larger, reaching values of up to 45%. The CO_2 gap ranges, either WLTP-based or NEDC-based are in line with the scientific literature (Ktistakis et al., 2021; TER, 2019).

Table 4: Global representations.

Fleet shares [%]			Trip shares [%]			Temperature shares [%]		
	EU	AU		Case 1	Case 2		EU	AU
V1	40	66	D1	34	34	T1	14	15
V2	26	17	D2	33	32	T2	27	22
V3	19	10	D3	24	28	T3	27	21
V4	15	7	D4	9	6	T4	20	17
						T5	12	25

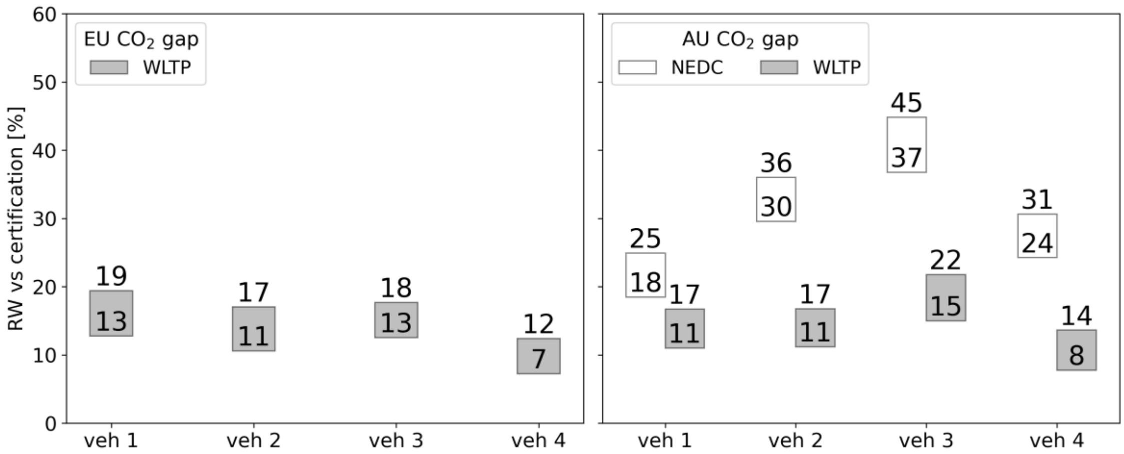

Figure 3: Individual vehicles CO_2 gaps. Left: EU; Right: AU. The bottom of each box represents the trips share case 2 and the top of the boxes are produced with the trips share case 1.

Combining the individual vehicles' annual gaps with the fleet shares data. The calculated EU SUV fleet CO_2 gap ranges between 12%-18% (WLTP). The calculated AU SUV fleet CO_2 gap ranges between 26%-32% (NEDC). Applying the WLTP certification procedure in AU, the certification values would be closer to the RW driving, thus the CO_2 gap would reduce to 11% to 17%.

Discussion and Conclusions

Two different markets were assessed for the year 2020: the EU market as the regulated market and AU as the unregulated market. Since there has been an upturn of SUVs worldwide the recent years, the study focused on these vehicles. A methodology is proposed to assess the two markets, combining representative vehicles, fleet data and environmental conditions from both regions with a simulation-based RW framework to perform a detailed analysis. The preliminary results quantify the performance of the SUVs in EU and AU, clearly showing a higher fuel efficiency of the EU vehicles. Using the simulation framework, the RW consumption was derived and also the CO_2 gap. The EU WLTP-based CO_2 gap is calculated to be around 18% and the AU NEDC-based CO_2 gap ranges up to 32%, with both figures being in line with existing literature. With the support of the simulation tool, the WLTP-equivalent CO_2 values for AU were derived, and the annual SUV fleet CO_2 gap dropped considerably and in the same levels as in EU. It should be acknowledged that other factors than regulation will shape a countries on-road fleet, and this will be further explored in future work. Despite any fallbacks experienced in the last decade, the EU fleet is transforming fast, while the opposite appears to be the case for AU. Furthermore, the WLTP protocol provides more realistic CO_2 and consumption values and supports building public awareness and making better choices for private commuting.

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