Electric Vehicles in Malaysia? Hold Your Horsepower!

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Abstract

In recent months, much debate has occurred surrounding the prospect of a new national car project, with a proposal for a locally-manufactured electric car company currently being developed by GreenTech Malaysia, an entity under the purview of the Ministry of Energy, Technology, Science, Climate Change, and Environment (MESTECC). Electric vehicles (EVs) have tremendous *potential* in the context of curtailing greenhouse gas emissions within the transportation sector, but only under the appropriate conditions. An often overlooked feature of EVs is that they shift the source of vehicular emissions from tailpipe to smokestack, and if electricity is predominantly generated from carbon-intensive sources such as coal, the environmental effects of vehicle fleet electrification may indeed be negative.

This analysis confirms those fears. With Peninsular Malaysia's current electricity grid mix, the average EV is more polluting than any petrol-powered vehicle that attains a fuel economy greater than 15.8*km*/*L*. To put this figure into context, the Perodua Bezza is capable of travelling 21*km* per *litre* of petrol; the truth is that many existing internal combustion engine vehicles (ICEVs), and indeed hybrid vehicles (HEVs), are capable of routinely exceeding this figure. At present, a shift to EVs is projected to increase aggregate vehicular emissions by between 10 and 48% (with an average of roughly 23%), depending on the vehicular energy efficiency, relative to a fleet composed of fuel-efficient ICEVs and HEVs. The situation improves for EVs as the share of renewable energy (RE) in electricity generation increases. However, it is only when the shares of coal and RE approach equality at around 35%, with the shortfall met by natural gas, that EVs are on average marginally cleaner than most ICEVs, and are more competitive with HEVs, in terms of their emissions impact. This highlights the dangers, from a climate change standpoint, of a premature focus on electric vehicles in Malaysia, and emphasises further the importance of a significant, long-run decarbonisation of the national electricity grid.

Rather than promote electric vehicles, the government should focus its attention on other policy measures that can play a role in mitigating emissions attributable to the transport sector in Malaysia *today*. The first is a revamp of the existing energy efficient vehicle policy, introduced by the Ministry of Trade and Industry (MITI) in 2014. This policy is at present too broad in its scope, too lenient in its requirements, and too opaque in its incentivisation structure; an overhaul is necessary to ensure its effectiveness from an environmental perspective. The second option is the implementation of national fuel economy standards, similar to those used in China, the EU, Japan, South Korea, and the US. With over half-a-million new vehicles sold in Malaysia annually since 2010, fuel economy standards, which mandate annual improvements in the energy efficiency of ICEVs and HEVs, are capable of driving steady reductions in the per-kilometre emissions associated with private road transport in Malaysia. The third measure is without doubt the most important: improvements to the accessibility, reach and use of public transport across the country. In the short- and medium-run, these policies are capable of significantly outperforming vehicle fleet electrification in the context of climate action.

The time will come for EVs to propel another wave of emissions reductions from the transport sector in Malaysia, but the country – and its electricity grid – simply isn't ready yet.

Contents

Figures and Tables

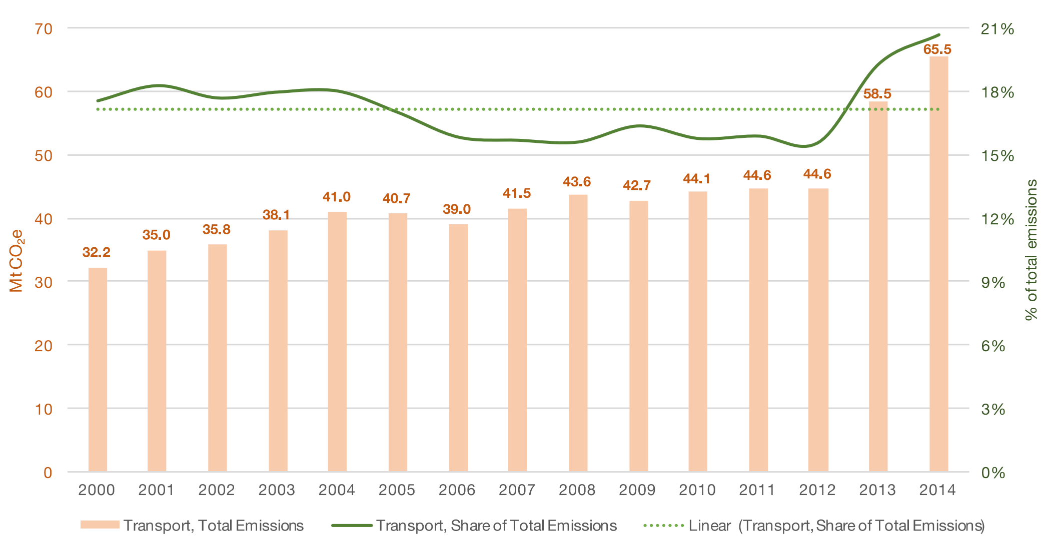
1 Introduction

Over recent months, talk has circulated across Malaysia of a new national car project. These debates were sparked by remarks made by Prime Minister Tun Dr Mahathir Mohamad at the *24th International Conference on the Future of Asia* in Japan in June, when he suggested Malaysia start a new national automotive company with the aim of making headway in global markets[1]. Public response to the idea of a third local manufacturer to follow Proton and Perodua has been mixed, with opponents suggesting that attention instead be diverted toward public transportation. They have a point. Measures that improve the accessibility and reach, and encourage the use, of public transport options in Malaysia should form a significant component of an effective plan to curtail greenhouse gas emissions within the transport sector at large.

As of 2015, the motorisation rate in Malaysia was highest amongst ASEAN nations, and four times the continental average, at 439 vehicles per 1,000 inhabitants[2]. Another national car project, in presumably adding to the size of the vehicle fleet, would only worsen traffic congestion, already a particularly pertinent issue in Malaysia's sprawling urban centres[3]. Crucially, it would likely hinder any effort to mitigate emissions within the transport sector.

Figure 1 charts the trajectory of national emissions, measured in CO_2-equivalence (CO_2e), from transportation between 2000 and 2014[4]. Within this period, emissions more than doubled, to 65$MtCO_2e$. In 2012, over 85% of transport emissions were attributed to road transport, of which cars and motorcycles were responsible for roughly 70%, or 38.7$MtCO_2e$[5]. There is enormous scope for significant climate action within this energy subsector, but this is unlikely to be realised with more cars on Malaysian roads.

Figure 1: Transportation Emissions in Malaysia



Source: World Resources Institute, Climate Analysis Indicators Tool

[1] https://asia.nikkei.com/Spotlight/The-Future-of-Asia-2018/Malaysia-weighs-new-national-carmaker-with-global-reach
[2] International Organization of Motor Vehicle Manufacturers (2015)
[3] Gil Sander (2015), of the World Bank, provides an extensive discussion on the prospects for urban transport in Malaysia.
[4] World Resources Institute: Climate Analysis Indicators Tool (2017)
[5] Gitano-Briggs & Leong (2016)

Attention has since honed in on the prospect of a national *electric* car project, a development spurred by concerns over climate change, as well as automotive industry trends pointing to a future of electrified – and eventually autonomous – vehicle fleets. In late July, the Malaysian Green Technology Corporation (also known as GreenTech Malaysia), an organisation under the purview of MESTECC, announced that it is currently drafting a national electric car proposal to be presented to the Ministry for approval at a later date[6].

Against such a backdrop, this study acts as a cautionary message to GreenTech Malaysia, MESTECC and other relevant government stakeholders: electric vehicles (EVs) are only as clean as the energy sources that power them[7], with emissions shifted from tailpipe to smokestack. Over 90% of Malaysia's electricity is generated through the burning of fossil fuels[8]; consequently, a focus on EVs without *first* addressing the composition of the electricity grid would be premature, and instead lead to a *rise* in the nation's transport sector emissions. This would be lamentable in the face of Malaysia's commitment to cutting GHG emissions by 45% by 2030[9], particularly considering that transport should make for one of the low-hanging fruit in the context of overall national emissions reductions.

This paper proceeds as follows: Section 2 outlines the methodology involved and assumptions made in estimating the per-kilometre emissions of EVs, ICEVs, and HEVs at varying electricity grid compositions. Section 3 presents the results of this analysis, while Section 4 highlights subsequent policy implications and recommendations. Section 5 provides a brief discussion of the limitations of this study, and Section 6 concludes.

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[6] https://themalaysianreserve.com/2018/07/26/electric-based-national-car-proposal-being-developed/
[7] Anair & Mahmassani (2012)
[8] Particular emphasis should be placed on the contribution of coal, at 57%.
[9] Referring to Malaysia's Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC)

2 Methodology

This section describes the methodological approach employed during the process of quantifying the CO_2e emissions impacts of EVs against those of ICEVs and HEVs. The outcome of interest in this study, therefore, is the number of grams of CO_2e emitted per kilometre for a range of vehicles utilising these drivetrain technologies. Equations 1 and 2 outline the simplified models used to estimate these impacts for both vehicle categories, with units of measurement listed in parentheses.

$$(1)\ EV\ Emissions\left(\frac{gCO_2e}{km}\right) = \left[E\left(\frac{kWh}{km}\right) \times GA_{CO_2e}\left(\frac{gCO_2e}{kWh}\right)\right] + MFG_{LC}\left(\frac{gCO_2e}{km}\right)$$

$$(2)\ ICEV\ \&\ HEV\ Emissions\left(\frac{gCO_2e}{km}\right) = \left[E\left(\frac{l}{km}\right) \times PA_{CO_2e}\left(\frac{gCO_2e}{l}\right)\right] + MFG_{LC}\left(\frac{gCO_2e}{km}\right)$$

where: *E* represents vehicle energy requirements;
$GA\text{-}CO_2e$ represents grid-average carbon intensity;
$PA\text{-}CO_2e$ represents petrol-average carbon intensity, and
MFG_{LC} refers to life-cycle emissions from vehicle manufacturing processes.

The remainder of this section elaborates on the individual components of each of the explanatory variables listed above, as well as the assumptions that have been made throughout the emissions estimation process.

2a *Energy Sources and Associated Life Cycle Emissions*

The major distinction between EVs, and ICEVs and HEVs, are in the sources of energy required for propulsion, with the former utilising electricity and the latter, petrol (or gasoline).

(i) Electricity Generation

Life-cycle emissions intensities of individual energy sources have been derived from a 2011 literature review conducted by the Intergovernmental Panel on Climate Change (IPCC)[10]. Handily, the IPCC review provides life-cycle emissions estimates for the minimum, median, maximum, and the 25th and 75th percentiles for a broad range of electricity generation technologies *in grams per kWh*, allowing for straightforward incorporation into calculations of EV emissions in this report. A breakdown of the IPCC's median emissions intensity estimates used in this analysis is provided in Table 1.

Table 1: Life-Cycle Emissions Intensities of Electricity Generation Sources (in gCO_2e/kWh)	
Coal	**1,001**
Natural Gas	**469**
Solar PV	**46**
Large-Scale Solar	**22**
Hydroelectric	**4**
Biomass	**18**

[10] Intergovernmental Panel on Climate Change (2011).

These figures have been used to determine grid-average carbon intensity (GACI) in Peninsular Malaysia, based on varying fuel mix compositions. At present, electricity across the country is predominantly generated through the burning of fossil fuels. The Energy Commission (EC) reports that, as of 2018, 57% of electricity on the peninsula is derived from coal, and 35% from natural gas[11]. The remaining 8% is equally split between renewable energy (RE) and large-hydro[12]. This current grid composition has been set as the baseline upon which automobile-related emissions are calculated. Various additional compositions are analysed, and these are listed in Table 2.

Table 2: Grid Compositions and Carbon Intensity		*Share (%) of:*			**Grid-Average Carbon Intensity (g/kWh)**
		Coal	**Natural Gas**	**Renewable Energy**	
1	Current Mix	57	35	8	*736.6*
2	PH Target A	49	27	24	*622.6*
3	PH Target B	41	35	24	*580.1*
4	LR Equivalence	35	30	35	*499.1*
5	All Coal	100	0	0	*1,001*
6	All RE	0	0	100	*23*

Of particular importance in the short-run are the *PH Target A* and *Target B* compositions. These refer to the pledge that the incumbent Pakatan Harapan (PH) government has made to boost the share of RE in electricity generation to 20% (or 24%, inclusive of large-hydro, in the context of this study)[13]. *Target A* makes up for the required 16% increase in the RE share through equivalent decreases in the contributions of coal and natural gas, while *Target B* does so solely through a decline in the share of coal[14]. *LR Equivalence* refers to a feasible longer-run state where the contributions of all these major energy sources lie largely at parity[15]. The *All Coal* and *All RE* metrics are self-explanatory, and serve to highlight both extremes of the emissions effects of vehicle fleet electrification. The GACI figures reported in Table 2 are directly used to project the emissions impact of various EVs across the different electricity grid compositions.

(ii) Petrol

Calculations of the life-cycle carbon emissions of petrol are split into two stages: well-to-pump (WTP), and pump-to-wheels (PTW). This allows for the derivation of a holistic estimate for the environmental effects of the production and use of petrol.

Estimations of up- and mid-stream emissions are derived from the per-barrel emissions of crude oil. The Carnegie Endowment for International Peace (CEIP) reports these figures[16] for various oils, including those of conventional light oil, taken in this context to reflect the emissions associated with oil produced in Malaysia. Of the total of 475*kg* of CO_2e released per barrel, 45*kg* is associated with up- and midstream activities. Assuming each barrel produces an average of 71.55 litres of petrol[17], a total of 20.25*kg*CO_2e is therefore emitted due to up- and mid-stream activities attributable to petrol alone. This translates to 283*g*CO_2e/*L*.

[11] Malaysia: Suruhanjaya Tenaga (2016)
[12] Purely for the purpose of simplicity, I have included the 4% figure for large-hydro within the category of RE, as the emissions intensities of all relevant energy sources falling under this category do not vary significantly. Further, the share of large-hydro is expected to remain constant for the foreseeable future. Large-hydro is *not* categorised as RE in Malaysia, owing to its vast environmental footprint.
[13] Malaysia: Pakatan Harapan (2018)
[14] In addition to highlighting the benefits of incorporating a larger share of renewables into electricity generation on emissions reductions, these two 'PH Target' scenarios underline the carbon intensity of coal relative even to other fossil fuels.
[15] Ideally this would be the target, inclusive of large-hydro, set for 2030, building upon the existing 20% target for 2025.
[16] https://carnegieendowment.org/2016/02/09/breaking-down-barrel-tracing-ghg-emissions-through-oil-supply-chain-pub-62722
[17] http://fingfx.thomsonreuters.com/gfx/rngs/1/1409/2220/index.html

In-use emissions of petrol are comparatively simple to estimate. Each litre of petrol contains around 630*g* of carbon; this means CO_2, with a molecular weight roughly 3.67 times that of carbon, is emitted at a rate of 2.31*kg* per litre during combustion. These figures match those reported by Canada's Department of Natural Resources[18], and the United States' Environmental Protection Agency[19]. It is therefore assumed that a total of 2,593*g* of CO_2e are emitted per litre of petrol, for ICEVs and HEVs.

2b *Manufacturing Emissions for ICEVs, HEVs, and EVs*

Emissions that accrue during the manufacture of vehicles are an important component of the comparison between drivetrains. This is because the production of EVs is strictly more carbon-intensive than that of petrol-engine vehicles; evidence suggests that, on average, roughly one-third of the life-cycle emissions associated with EVs accrue during production, compared to a tenth for ICEVs. In absolute terms, the production emissions of HEVs track those of ICEVs closely[20]. The omission of manufacturing emissions would thus understate the environmental impacts of EVs, relative to the competing technologies. Another factor that supports the inclusion of these emissions is the assumption that any potential *national* electric car project would entail *local* production of these vehicles and, as a result, any emissions arising during the manufacturing process would count towards Malaysia's greenhouse gas inventory.

Manufacturing emissions data for ICEVs, HEVs, and EVs is drawn from Gbegbaje-Das (2013), who estimates total CO_2 emissions throughout the life-cycles of a variety of vehicle technologies in 2012, 2020, and 2030[21]. Gbegbaje-Das splits production emissions into two stages: component manufacture, and vehicle assembly, and assumes a total vehicle lifetime mileage of 150,000*km*[22]. Across time periods, emissions during these stages are postulated to be simultaneously affected by two 'shocks': decreases in the quantity of raw materials consumed in vehicle production, and improvements to GACI. In other words, projections of manufacturing emissions in 2030, for instance, are reflective of predetermined reductions in the carbon intensities of *both* automotive component requirements and of electricity generation, relative to 2020 levels. The posited relationships between these variables have been fitted to suit the grid compositions under analysis in this study, and used to estimate per-kilometre manufacturing emissions within the context of Malaysia. These relationships, between GACI, vehicle material requirements, and the emissions associated with both manufacturing stages, are presented in Appendix Section 7a. An overview of total manufacturing emissions, by electricity grid composition and vehicle type, is presented in Table 3.

Table 3: GACIs and Vehicle Manufacturing Emissions		**Total Manufacturing Emissions (g/km)**	
		EVs	***ICEVs***
1	**Current Mix**	83.10	48.61
2	**PH Target A**	77.25	45.45
3	**PH Target B**	75.15	44.30
4	**LR Equivalence**	71.27	42.15
5	**All Coal**	98.03	56.45
6	**All RE**	51.21	30.56

[18] http://www.nrcan.gc.ca/energy/efficiency/transportation/cars-light-trucks/buying/16770
[19] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100U8YT.pdf
[20] See Section 2 of Anair & Mahmassani *(footnote 7)* for a discussion on the manufacturing emissions of ICEVs and EVs.
[21] Gbegbaje-Das (2013)
[22] With annual mileage in MY roughly 24,000*km*, this lifetime mileage assumption is equivalent to using a car for 6¼ years.

The assumptions held throughout the derivation of vehicle manufacturing emissions pertain to the characteristics of the base vehicles used[23]. For ICEVs, the reference is a mid-size car, e.g. Volkswagen Golf or Ford Focus, with a weight of roughly 1,240*kg*. For EVs, the reference is again a mid-size car, e.g. Nissan Leaf, with a weight of roughly 1,530*kg* and a lithium-ion battery pack with a capacity of 24*kWh*. In calculating manufacturing emissions at various future states, Gbegbaje-Das assumes reductions in the carbon intensity of raw material requirements over time, through increasing light-weighting of all vehicle types, as well as improvements to battery technology used in EVs. As such, changes in manufacturing emissions across various grid compositions are not solely due to changes in GACI. Given that the manufacturing emissions of HEVs only slightly exceed those of ICEVs, these vehicle technologies are assumed to have equivalent production-stage emissions and are consequently categorised together.

The use of baseline vehicles whose specifications conform to the average mean that manufacturing emissions associated with larger-than-average vehicles are likely to be slightly understated, and those associated with smaller-than-average vehicles are likely to be slightly overstated. This, however, does not pose a significant threat to the validity of the estimates presented in Table 3, for two reasons. First, ICEVs and EVs are both affected similarly, in directionality and magnitude. Second, the difference across vehicle types *of* the differences between a more precise measure that utilises base vehicles which vary by size and the measure used in this analysis, is likely small, and therefore would not significantly influence the overall results presented in Section 3.

2c *Energy Use: Fuel Economy and Electric Efficiency*

The next stage focuses on the metrics which reflect the energy use, and energy use requirements, of both petrol- and electricity-powered vehicles. For ICEVs and HEVs, in the context of this study, this refers to fuel economy (*km/L*); for EVs, emphasis is placed on electric efficiency (*kWh/100km*).

The range of fuel economy measures under analysis lie between 10 and 28*km/L*, with the Malaysian average (global average) at 14.3*km/L* (13.2*km/L*) in 2015[24]. As the results presented in Section 3 will show, there is no real benefit to extending the range of fuel economies downwards, as ICEVs are, at 10*km/L* (or lower), already more polluting than all EVs, given Malaysia's current and projected future GACIs. There is also no present need to extend the range upwards; the United States' Department of Energy records the highest fuel economy in 2018 at 25.7*km/L*[25]. While this figure will likely rise over time, meaningful lessons can nevertheless still be derived from the selected range of fuel economy in this analysis

The range of electric efficiencies analysed also lie between 10 and 28*kWh/100km*. This range encompasses the average efficiency of all EVs in neutral, favourable, and unfavourable conditions, as reported by the EV Database[26]. That they are in numerical terms equivalent to the ICEV and HEV range allows for straightforward graphical representation of the situations in which EVs are more environmentally beneficial than ICEVs and HEVs, and vice versa.

[23] As the figures derived for manufacturing emissions are drawn from Gbegbaje-Das (2013), the calculations in Table 3 reflect the same base vehicle specifications used by the author.

[24] International Energy Agency (2017); the quoted figure for Malaysia is an average of NEDC and WLTC measurements.

[25] The DoE cites the Hyundai Ioniq Hybrid as the petrol-based vehicle with the highest fuel economy.

[26] In neutral conditions, the range of average EV efficiency, by vehicle, is between 14.29 and 23.3*kWh/100km*. In favourable conditions, between 12.43 and 20.19*kWh/100km*. In unfavourable conditions, between 17.4 and 27.03*kWh/100km*.

3 Results

High-level illustrations of the results of this analysis, based on the methodology and assumptions described in Section 2, are provided in Figure 2 and Figure 3. In Figure 2, each EV emissions curve is associated with a particular electricity grid composition; reductions in the carbon intensity of electricity generation contribute to downward shifts in the emissions curves. The magnitude of the difference in the life-cycle emissions intensities of EVs across varying electricity grid compositions is striking. The average EV, which requires roughly 17.55*kWh* to travel a distance of 100*km*, emits 274*g*CO_2e/*km* if the electricity grid is reliant solely on coal, compared with just 54*g*CO_2e/*km* if the electricity grid is reliant solely on renewables. Given Malaysia's *current* electricity generation mix, the average EV emits 212*g*CO_2e/*km*. The achievement of Pakatan Harapan's RE goals would curtail this figure to 187*g*CO_2e/*km* should the shares of coal and natural gas be decreased equivalently *(PH Target A)*, and 177*g*CO_2e/*km* if only the share of coal is decreased *(PH Target B)*. While changes to the energy efficiency of EVs, represented by movements along the relevant emissions curve, do impact the emissions intensity of these vehicles, the carbon intensity of electricity generation is the main determining factor of the potential of EVs to contribute to effective climate action[27].

Figure 2:
Per-Kilometre EV Emissions at Varying Electricity Grid Compositions

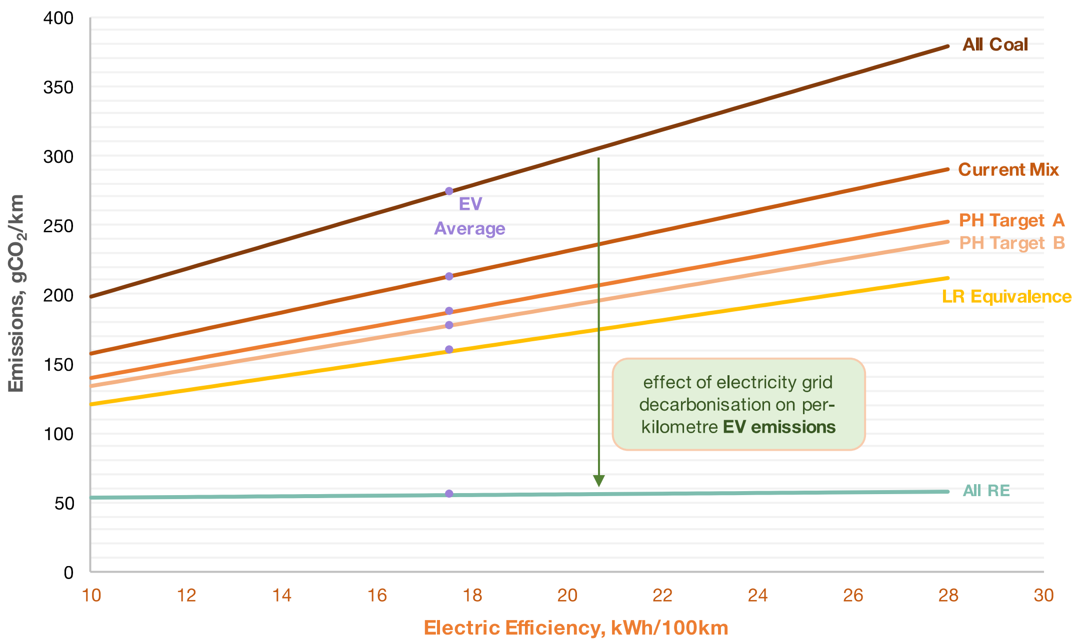


Figure 3 highlights the per-kilometre emissions of ICEVs and HEVs at four different electricity grid compositions[28]. The differences in emissions across electricity grids are driven primarily by changes in the carbon intensities of the component manufacture and vehicle assembly processes, as described in Section 2b, and *not* by those during vehicle usage. It is important to note that a key difference in the way that the data is represented in these figures relate to the units used on the horizontal axis: for EVs, this is framed in

[27] It is also noticeable through Figure 2 that the impact of electric efficiency on per-kilometre emissions decrease with reductions in grid-average carbon intensity.

[28] The *PH Target A* and *B* grid compositions have been left out of Figure 3 only because they are superfluous in conveying the message that ICEV and HEV emissions do not vary significantly with the carbon intensity of electricity generation. The magnitude of the maximum disparity in the emissions of petrol-powered vehicles between the current electricity generation mix and the *LR Equivalence* composition is under *6 grams*, and the disparity between the two PH targets is smaller still.

terms of energy use per unit of distance; for ICEVs and HEVs, this is framed in terms of distance travelled per unit of energy[29]. Unlike EVs, whose environmental impacts are dependent on the composition of the electricity grid, the most important factor determining the per-kilometre emissions of an ICEV or HEV is its fuel economy: an ICEV that travels 21*km* per litre of petrol emits 172.1*g*CO_2e/*km* while one which attains a fuel economy of 15*km*/*L* emits 221.5*g*CO_2e/*km*, almost 50*g* more per kilometre.

Figure 3:
Per-Kilometre ICEV & HEV Emissions at Varying Electricity Grid Compositions

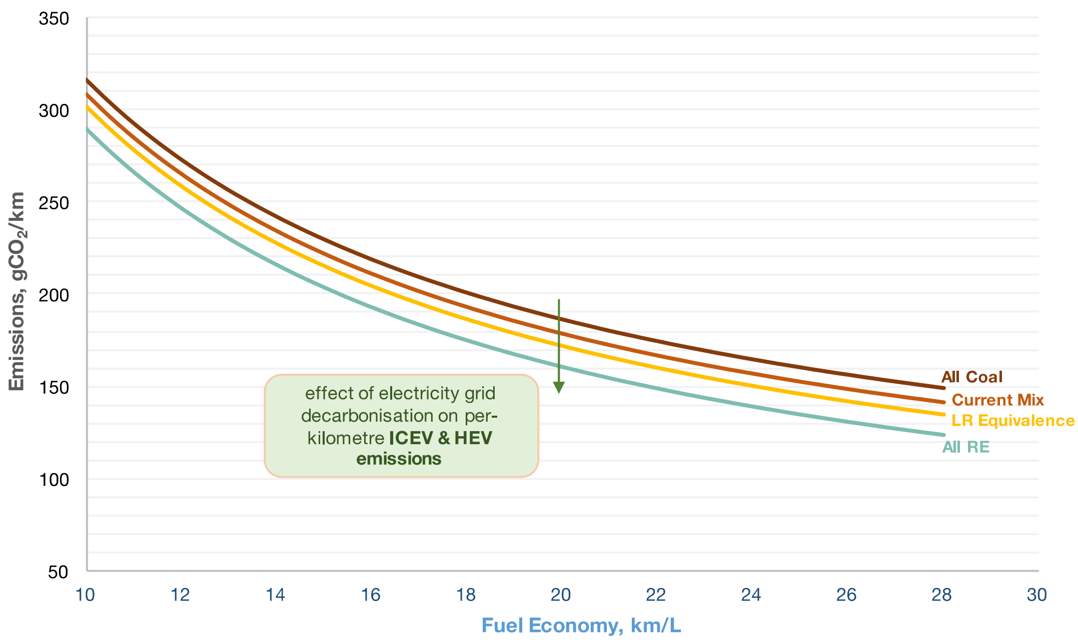
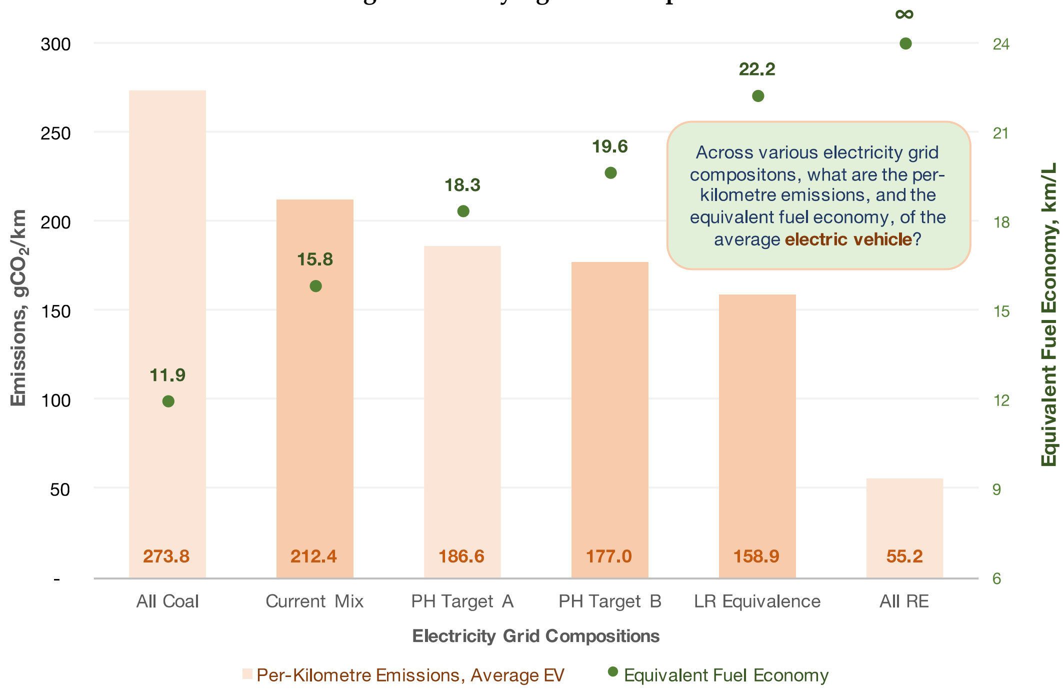


Figure 4 offers an alternative representation of these key takeaways. Highlighted here are the per-kilometre emissions, and the equivalent fuel economy, of the average EV across the varying grid compositions listed in Table 2. This is a useful measure as it identifies the specific fuel economy ratings at which ICEVs and HEVs are more environmentally beneficial than EVs, at a particular carbon intensity of electricity generation. This information can be used to inform policies which address petrol-powered cars from an environmental perspective, including through the provision of incentives for fuel efficient vehicles, and the setting of fuel economy standards. This will be discussed in greater detail throughout Section 4.

Figure 4 reveals that, given Malaysia's current electricity generation mix, the average EV is as polluting as an ICEV or HEV, with a fuel economy of 15.8*km*/*L*; at PH Target A this figure rises to 18.3*km*/*L*, and at Target B to 19.6*km*/*L*. If electricity is generated roughly equally between coal, natural gas, and RE, the average EV is cleaner than ICEVs and HEVs which attain any less than 22.2*km*/*L*. The reader is invited to contrast these figures with those achieved in their own vehicles: a wide variety of *existing ICEVs*, let alone HEVs, achieve fuel economies which make them cleaner than the average EV – even at electricity grid compositions with a lower carbon intensity.

[29] These follow the conventional norms of expression for electric efficiency, and fuel economy, respectively.

Figure 4: Emissions, and Equivalent Fuel Economy, of the Average EV at Varying Grid Compositions



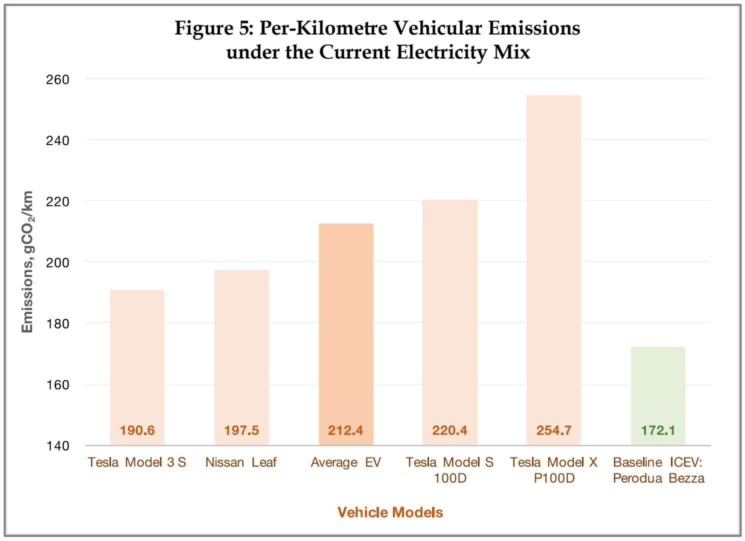
Given that there is much scope for further increases to fleet-wide fuel efficiencies of ICEVs and HEVs through a combination of policy action and technological development, there is a need to review and question the environmental benefits of EVs, in both the short- and medium-run. With this overarching framework of results in mind, the remainder of this section will analyse in greater depth EV emissions under select electricity grid compositions.

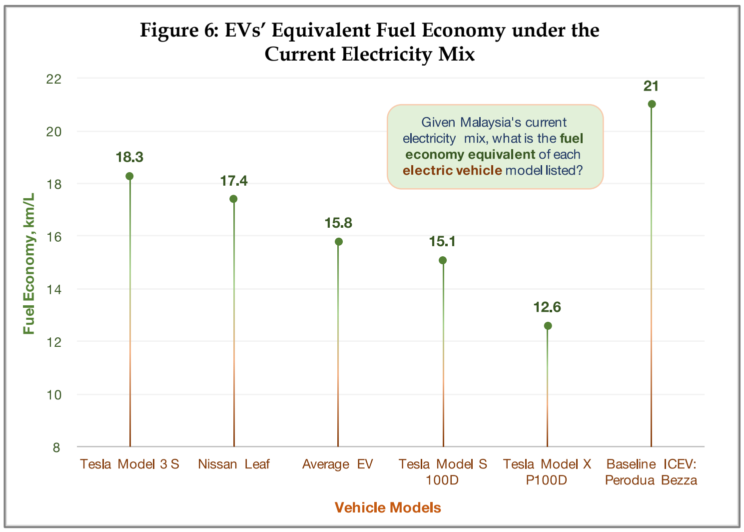
3a EVs versus ICEVs and HEVs: Current Electricity Grid Composition

Figure 4 reveals that, under the current electricity generation mix, ICEVs and HEVs which exceed a fuel economy of 15.8km/L are more beneficial to the environment than the average EV. Figure 5 analyses the emissions performances of a selected sample of EVs under the current electricity grid composition, against that of the Perodua Bezza, which achieves a fuel economy of 21*km*/*L* and is amongst the most fuel-efficient ICEVs on sale in Malaysia. This sample of EVs has been chosen to reflect a wide range of electric efficiency levels, and includes the Tesla Models 3, S, and X, as well as the Nissan Leaf. Tesla's Model 3 is amongst the most efficient EVs currently on North American markets, whilst the Nissan Leaf is representative of the average *compact* EV. The electric efficiency level of the average EV, which as stated at the start of Section 3 lies at 17.55*kWh*/100*km*, is derived from the average electric efficiencies of a sample of 33 EVs currently available on one or more international markets, with the efficiency data of each individual model drawn from the Electric Vehicle Database[30].

Figure 5 highlights that, under the present electricity mix, the Perodua Bezza emits 18.5*g*CO_2e/*km* less than one of the most efficient EVs currently in production, over 40*g* less than the average EV, and more than 80*g* less than an inefficient EV such as Tesla's Model X. Figure 7, meanwhile, calculates the fuel economy equivalent, in terms of per-kilometre emissions, of each of these EVs. The average EV is as

[30] https://www.ev-database.uk





polluting as ICEVs and HEVs attaining a fuel economy of 15.8*km*/*L*, while those which attain a fuel economy greater than 17.4*km*/*L* are less polluting than most compact EVs. Even the most efficient EV is outperformed in emissions terms by ICEVs and HEVs with a fuel economy greater than 18.3*km*/*L*; this means that the Perodua Bezza and the Toyota Camry Hybrid (19.2*km*/*L*), for instance, are both more beneficial to the environment than almost all EVs. It is worth noting that the Camry Hybrid is itself less efficient than many other HEVs, including the Toyota Prius, Honda Jazz, and Hyundai Ioniq. The Proton Saga (18.2*km*/*L*), meanwhile, is roughly on par with the Tesla's Model 3, and Perodua's Myvi (17.3*km*/*L*) with compact EVs. On the bottom end of the scale, Tesla's Model X is outperformed on emissions by the BMW X4 (13.7*km*/*L*). Given the weight of evidence, an electrification of Malaysia's vehicle fleet, under the current electricity grid mix, will very likely be detrimental from the perspective of emissions within the transport sector. A better policy target should instead incentivise the use of fuel-efficient ICEVs and HEVs.

3b *EVs versus ICEVs and HEVs: Future Electricity Grid Compositions*

The cleanliness of EVs improves with reductions to the carbon intensity of the national electricity grid; as Figure 2 suggests, an electric car powered fully by renewables is almost unfathomably clean. Two of the potential future-grid scenarios listed in Table 2 are analysed within this section: *PH Target B*, comprised of 41% coal, 35% natural gas, and 24% RE; and *LR Equivalence*, comprising 35% coal, 30% natural gas, and 35% RE.

(i) ***Pakatan Harapan Target B*: 41% Coal, 35% Natural Gas, 24% RE**

Figure 7 and Figure 8 replicate the analysis conducted in Figure 5 and Figure 6, albeit assuming the achievement of the government's 2025 electricity grid target of 20% RE penetration (or 24%, inclusive of large-hydro), at the expense of a 16% reduction in the share of coal. This decrease in the carbon intensity of electricity generation is reflected by an upward shift in the equivalent fuel economy ratings of the sample of EVs under analysis. At this point, both Tesla's Model S, and Nissan's Leaf are slightly less polluting than the Perodua Bezza; Figure 8 reveals that the Model S is outperformed only by ICEVs and HEVs achieving

Figure 7: Per-Kilometre Vehicular Emissions under the *'PH Target B'* Electricity Mix

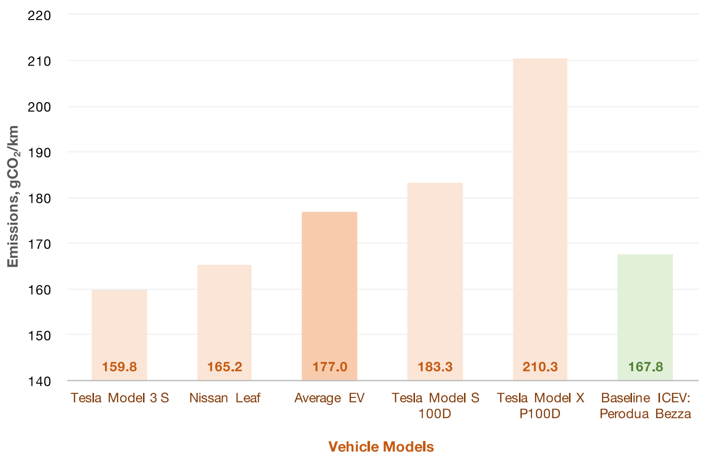
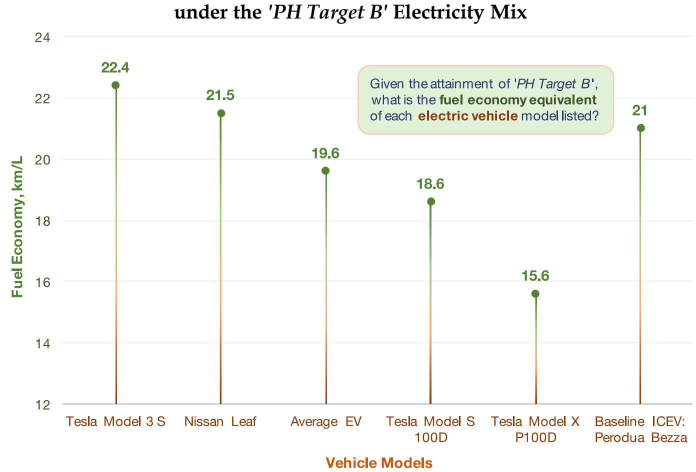


Figure 8: EVs' Equivalent Fuel Economy under the *'PH Target B'* Electricity Mix



a fuel economy greater than 22.4*km*/*L*, and the Leaf (and by extension, most compact EVs) by those with a fuel economy rating of at least 21.5*km*/*L*. The average EV, however, is still more polluting than the Bezza, and marginally better than the Camry Hybrid – though other HEVs are likely to be less emitting still. In any case, this is indicative of the magnitude of the effect of electricity grid decarbonisation on the potential for EVs to contribute meaningfully to effective climate action in Malaysia.

At the same time, it is important to be mindful of the fact that any improvements to the energy efficiencies of ICEVs, HEVs, and indeed EVs, could alter the complexion of this picture. Average fuel economies across petrol-powered engines have been increasing steadily year-on-year[31], particularly in markets with enforced fuel economy standards, including the United States, the European Union, Japan, and South Korea. This indicates that there is clear upward potential in the efficiency of ICEVs and HEVs in Malaysia over the short-term. Whether this potential can be matched by EVs in the immediate future is less clear; attention within the EV industry at present is focused less on energy efficiency, and more on issues pertaining to vehicle range and charging times, for instance. In any case, the relative inefficiencies of particular EV models are primarily driven by vehicle weight. Reductions on this front are a hurdle that must be passed in order for EVs to achieve improvements in average electric efficiency.

It is therefore reasonable to project that improvements to the fuel economy of ICEVs and HEVs will outstrip improvements to the electric efficiency of EVs, at least in the short-run. Should improvements to the average efficiency of petrol-powered cars outpace that of EVs by, say, 10% from current levels, by 2025, the Camry Hybrid and Bezza would all contribute more to emissions reductions than the average *compact* EV, even at *PH Target B*. This adds doubt on the ability of EVs to contribute to emissions reductions from private road transport in Malaysia even if some steps towards electricity grid decarbonisation are taken; in fact, the net effect may still be negative. From the perspective of climate change action, this is a risk that cannot be taken when other, more effective policy options are available, other than vehicle fleet electrification.

[31] https://www.epa.gov/fuel-economy-trends/highlights-co2-and-fuel-economy-trends

(ii) *LR Equivalence: 35% Coal, 30% Natural Gas, 35% RE*

Figure 9: Per-Kilometre Vehicular Emissions under the *'LR Equivalence'* Electricity Mix

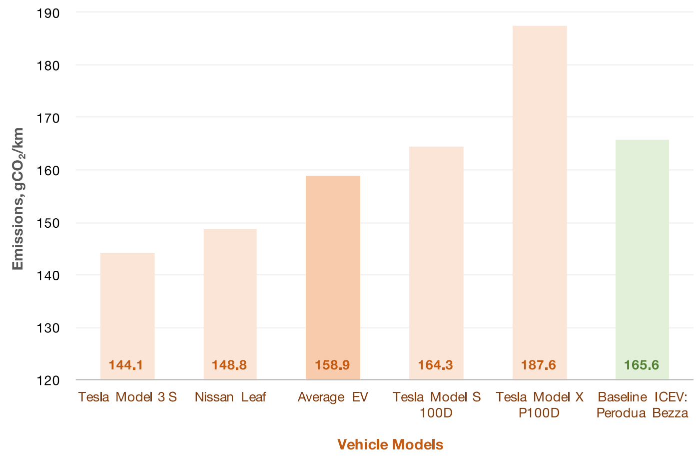
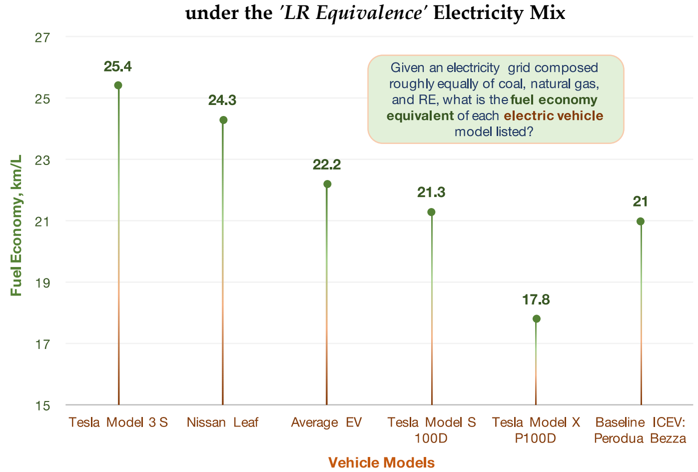


Figure 10: EVs' Equivalent Fuel Economy under the *'LR Equivalence'* Electricity Mix



The per-kilometre emissions and equivalent fuel economy ratings of EVs, given an electricity grid roughly equally composed of coal, natural gas, and RE, are presented in Figure 9 and Figure 10. This grid mix represents just under a one-third reduction in GACI from current levels, and under these conditions, the average EV outperforms most currently-available ICEVs on emissions, and is competitive with most compact HEVs, such as the aforementioned Prius, Jazz, and Ioniq models. Tesla's Model 3, along with the Nissan Leaf and most compact EVs, represent significant improvements on most present-day ICEVs and HEVs from the perspective of climate action. Importantly, even an energy-guzzler such as the Tesla Model X is less polluting than the Perodua Myvi, and only slightly more so than the Proton Saga.

Together with the analysis conducted throughout Section 3, this evidence suggests that it is only as the electricity generation composition approaches a situation where the contributions of coal and RE lie largely at parity that steady and significant emissions reductions can be expected from vehicle fleet electrification. At this stage, even the less-efficient EVs, represented by Tesla's Model X, are competitive with modestly-sized ICEVs, and produce lower emissions than ICEVs which attain any less than 17.8*km/L*[32]. Any future electrification of Malaysia's vehicle fleet should therefore be delayed until the country approaches a stage where renewables contribute to at least a third of national electricity generation. This is unlikely to be achieved by 2025, at which point the government is targeting an RE-plus-large-hydro penetration of 24%, but is a feasible target for 2030.

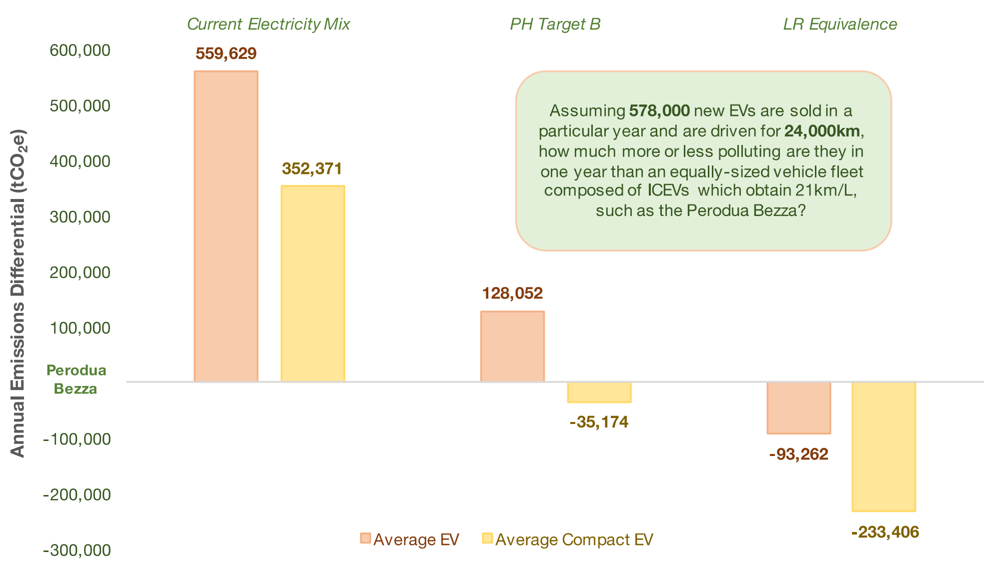
This timeframe provides the relevant Ministries with time to prepare the necessary infrastructure for an eventual EV transition, and crucially, as will be clear through Section 4, the space to implement alternative measures that, in targeting ICEVs and HEVs, would serve to curb emissions associated with private transport in Malaysia in the short- and medium-run. Note that more detailed graphical representations of the results of the analysis conducted in Sections 3a and 3b are provided in Appendix Section 7b.

[32] Though it is important to acknowledge the impact of future improvements to average fuel economy ratings of ICEVs and HEVs, which would raise the emissions standards required of EVs to remain competitive from an environmental standpoint.

3c *Aggregating Annual Fleet-Wide Emissions*

The lessons of this analysis are clear; electric vehicles are beneficial *only if* the composition of the electricity grid permits it. But just how beneficial (or not) are they, in the context of aggregate emissions reductions (or increases)? Thus far, the analysis has focused on individual vehicle emissions over a single kilometre. Figure 11 projects the estimated differential, across grid compositions, between the total fleet-wide emissions of EVs sold in a particular year, and those of a baseline ICEV fleet, of an equivalent size, with an average fuel economy of 21*km/L*[33]. This particular figure has been selected to reflect the Perodua Bezza and is representative of a standard, high-fuel efficiency vehicle. Two variations of EVs are analysed; the average EV[34] which utilises 17.55*kWh/100km*, and a more efficient, compact EV (based on the Nissan Leaf) which requires 15.53*kWh* per *100km*. Two further assumptions have been made in estimating annual fleet-wide emissions: firstly, that each vehicle is projected to travel a total of 24,000*km*[35], and secondly, that the size of the vehicle fleet is set at 578,000[36].

Figure 11:
New Fleet Emissions: Average EVs vs. ICEV Baselines Across Grid Compositions



These results reinforce the notion put forth in Sections 3a and 3b that an electrification of Malaysia's new vehicle fleet would be calamitous under the existing electricity grid composition, even amongst more energy-efficient EVs. A vehicle fleet composed of fuel-efficient ICEVs would emit almost 560,000tCO_2e less than one composed of EVs whose efficiencies conform to the average, and over 350,000tCO_2e less than those which more closely resemble a compact EV. The directionality and magnitude of these changes is striking, considering that EVs are heralded as a blessing to the environment, and that total emissions from private road transport stood at 38.7$MtCO_2e$ in 2015. Within a year, a new vehicle fleet could be deployed which would contribute greatly to climate change, rather than act against it. From the perspective of emissions reductions, a fuel-efficient fleet of ICEVs and HEVs would be preferable.

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[33] A higher-than-average fuel economy has also been selected to circumvent the concern over the prior non-incorporation of the expected over-time increases in average ICEV and HEV fuel economy ratings. Similar efforts are made with regard to a possible increase in the electric efficiency of EVs, through the inclusion of 'compact EV average'.
[34] This refers to the same 'average EV' used in prior stages of the analysis.
[35] Shabadin, Johari & Jamil (2017)
[36] This is a reflection of the average number of vehicles sold in 2016 and 2017, as reported by the Malaysian Automotive Association.

These negative effects persist even if PH's RE goals are met by 2025, with the benefits of compact EVs only marginally outweighing those of fuel-efficient ICEVs, assuming the same 21*km/L* fuel economy. As described earlier, however, increases in the average fuel economy of new ICEVs would put them ahead of most EVs in terms of emissions.

Table 4 broadens the scope of these results by highlighting the emissions impact of each of the EV models analysed throughout this study, relative to those of the Perodua Bezza, at varying electricity grid compositions. At the current electricity mix, vehicle fleet electrification is projected to lead to an increase in emissions of between 10 and 48%, relative to a vehicle fleet composed of fuel-efficient ICEVs. The variation between these figures is driven by EV fleet efficiency; if these EVs conform to the average, emissions are projected to rise by just over 23%, while if they are more closely represented by compact EVs, the emissions increase is estimated at roughly 15%. Once the government's RE targets are met, these compact EVs are marginally more beneficial than ICEVs and HEVs with fuel economy ratings akin to that of the Bezza, with emissions reductions estimated at just under 5%. At this stage, however, the average EV would still contribute to an increase in emissions, and inefficient EVs could contribute to a 25% rise in emissions over the baseline Bezza. Steady reductions in emissions from vehicle fleet electrification are likely only as Malaysia approaches a grid composition where the shares of coal, natural gas, and renewables are largely equivalent, and if the EVs in question utilise electricity efficiently. It is therefore imperative that *beyond* 2025, energy policy in Malaysia continues to focus on boosting the share of clean energy in electricity generation, while reducing the shares of fossil fuels. This would allow for the possibility of a *long-run* transition to an electrified vehicle fleet contributing greatly to a future wave of emissions reductions within the private transport sector in Malaysia.

Table 4: Relative Emissions Across Vehicle Models and Electricity Grids		*Relative Emissions (%)*		
Vehicle Models		**Current Mix**	**PH Target B**	**LR Equivalence**
1	**Perodua Bezza**	**100**	**100**	**100**
2	Tesla Model 3 S	110.8	95.3	87.0
3	Nissan Leaf	114.8	98.5	89.8
4	Average EV	123.4	105.5	95.9
5	Tesla Model S 100D	128.1	109.2	99.2
6	Tesla Model X P100D	148.0	125.4	113.2

4 Policy Implications

This analysis carries heavy implications for the prospect of a national electric car project. It is imperative that emphasis is placed, first and foremost, on the prospect of emissions reductions in the development of any policy measure that significantly affects the transport sector; despite the fact that EVs have tremendous potential in this respect, this potential will not be fulfilled in Malaysia until the electricity grid is sufficiently decarbonised. This entails Malaysia meeting the RE targets set forth in the PH manifesto, and more. Should the goal of 20% RE (24% including large-hydro, in the context of this study) in electricity generation be met by 2025, the environmental benefits of EVs relative to ICEVs is only marginal, and HEVs will likely constitute the most environmentally-friendly option for private transport. The picture brightens as the share of RE increases further; if Malaysia can achieve a one-thirds RE penetration by 2030, emissions reductions in transport, through an electrification of the vehicle fleet, will be possible. EVs provide yet another reason to engage in a steady, persistent, and long-term shift away from coal-fired electricity generation[37].

While a shift towards EVs represents a financially- and environmentally-costly prospect at present, other more attainable and promising policies can also play a role in engendering emissions reductions within private road transportation as Malaysia embarks on a long-run decarbonisation of its electricity grid.

4a Revamping the Energy Efficient Vehicle (EEV) Policy

In the short-run, the Energy Efficient Vehicle (EEV) program introduced by MITI as part of the 2014 National Automotive Policy (NAP) should be revamped[38], with the aim of specifically targeting modest, high-efficiency petrol-powered vehicles. The status quo arrangement, which incentivises automakers to meet fuel economy ratings based on vehicle weight, simply does not go far enough to ensure tangible environmental benefits from this policy.

The leniency of the Malaysian EEV standards are put into perspective in Figure 12. Here, EEV requirements are contrasted against mandatory fuel economy standards put in place in China[39], Japan[40], and South Korea[41]. Simply put, Figure 12 illustrates the fact that, to an extent, some cars which are able to achieve EEV status in Malaysia are too polluting to even be sold in Chinese, Japanese, and Korean markets. This disparity reflects poorly on the policy as it stands; amendments are needed to reflect increased stringency, and a narrower scope. A vehicle which weighs 2,500kg and achieves a fuel economy of 8.5km/L may be efficient for its weight, but in the wider context of a vehicle fleet in which smaller vehicles are capable of breaking the 20km/L barrier, large vehicles simply do not represent a good option from the perspective of climate change action. Instead, efficiency requirements should be more straightforward: at least 20km/L, regardless of weight[42].

It may be beneficial for discussions to commence between Malaysia, Indonesia, and Thailand over the standardisation of the definitions of energy-efficiency across the three countries. At present, Malaysia's EEV, Thailand's 'Eco-Car', and Indonesia's 'Low Cost Green Car' policies are effectively engaged in competition to attract automotive industry investment and jobs into national markets. Each national policy

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[37] It simply cannot be stressed how important it is that electricity grid decarbonisation transcends politics; regardless of whether the incumbent government or an opposition coalition triumphs in GE15, or 16, or 17, Malaysia must shift away from coal.

[38] Malaysia: Ministry of International Trade and Industry (2014)

[39] International Council on Clean Transportation (2014)

[40] Japan: The Energy Conservation Center (2011)

[41] Republic of Korea: Ministry of Environment, Traffic Environment Section (2014)

[42] Such a change would see Malaysia's EEV policy track more closely to Thailand's 'Eco-Car' and Indonesia's 'Low Cost Green Car' policies. Both countries impose maximum engine capacity limits (1.3L for petrol variants; 1.5L for diesel), and minimum fuel economy requirements (20km/L in Indonesia; 23.25km/L in Thailand).

offers various fiscal incentives to automakers in exchange for local component production and vehicle assembly, provided that these automakers meet the stipulated conditions concerning vehicle fuel efficiency[43]. Such circumstances may lead to a 'race to the bottom' where, in the interest of attracting investment ahead of their competitors, each of these nations either relaxes the requirements, or ratchets up the incentives, offered to automakers. Ultimately, this would likely benefit automakers themselves, ahead of national interests. There is consequently value in policymakers across these neighbouring states deliberating a more cohesive, regional EEV policy framework that would maximise regional utility, rather than of the 'winning' country alone. Such a move would set a positive precedent for future engagement on topics pertaining to climate change at-large; the most efficient way to address present-day environmental issues is through not just multinational, but global cooperation.

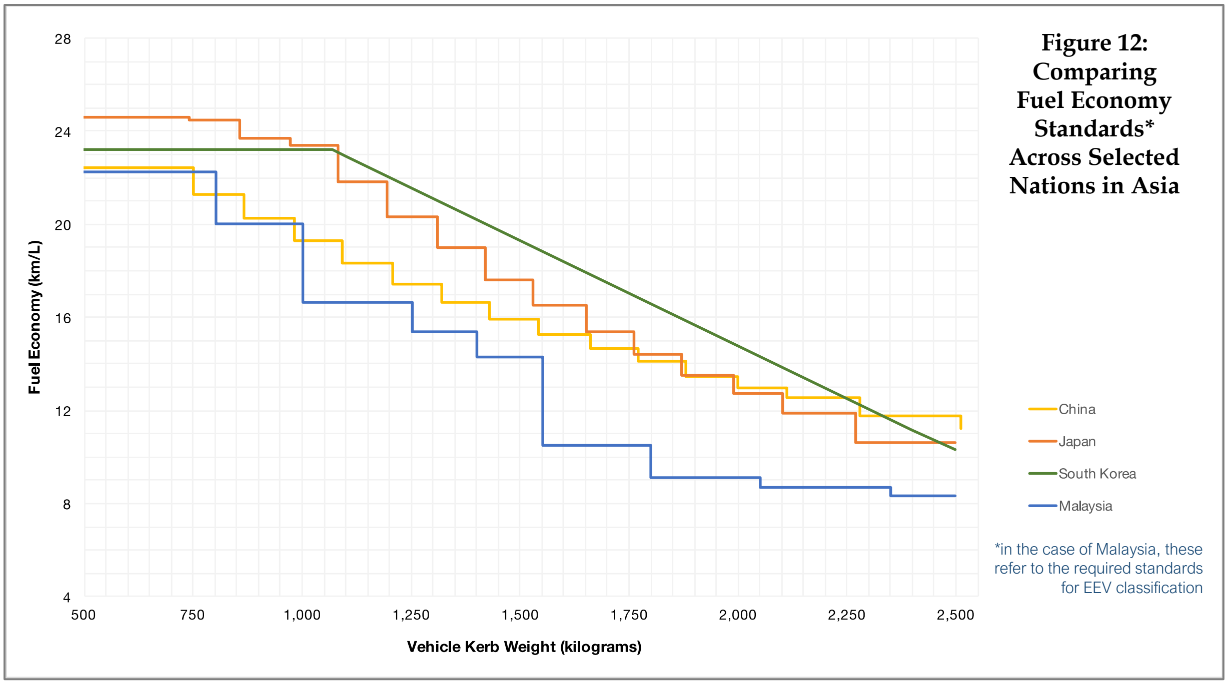

Figure 12: Comparing Fuel Economy Standards* Across Selected Nations in Asia

4b *The Role of Mandatory National Fuel Economy Standards*

While reviewing the existing EEV framework, MITI, MESTECC, and the Ministry of Transportation should consider the implementation of national fuel economy standards, in line with those implemented in China, Japan, and South Korea (as well as the European Union and the United States, amongst others). Such a policy has the potential to play a pivotal role in mitigating emissions associated with private road transport in the short- and medium-run. Already, this analysis has highlighted the importance of increasing the fuel economy ratings of ICEVs and HEVs in reducing the environmental impacts associated with private road transport. This is especially the case given that EVs are unlikely to make for a saviour given the carbon intensity of the current (and indeed achievable short-term) electricity grid composition(s).

Rather than merely incentivising the production of high-efficiency vehicles, fuel economy standards are mandatory; new vehicles which do not meet required emissions standards will be disallowed from being sold in Malaysia. The postulated effects of such a policy are illustrated in Figure 13; fuel

[43] Of the three policies, the incentives offered under Malaysia's program are the most opaque; the NAP cites the 'provision of customised incentives to attract strategic investments in the EEV category', without elaborating further on the nature of these incentives. This is a concern; under the PH government, the incentives offered to automakers must be made more transparent.

economy standards would have the impact of driving individual car model data points further down the ICEVs & HEVs curve, and consequently lower the CO_2e emissions associated with new petrol-powered cars. This, in turn, raises the bar that EVs need to meet; these competing propulsion technologies need to compete on the basis of their contribution towards effective climate action. Furthermore, given the already-high motorisation rates nationwide, there is clearly a need for policy measures that positively affect the *sustainability* of transport in Malaysia: minimising the carbon footprint of private vehicles, and improving public transport networks, particularly in and around urban centres[44]. The implementation of national fuel economy standards would be a step in this direction.

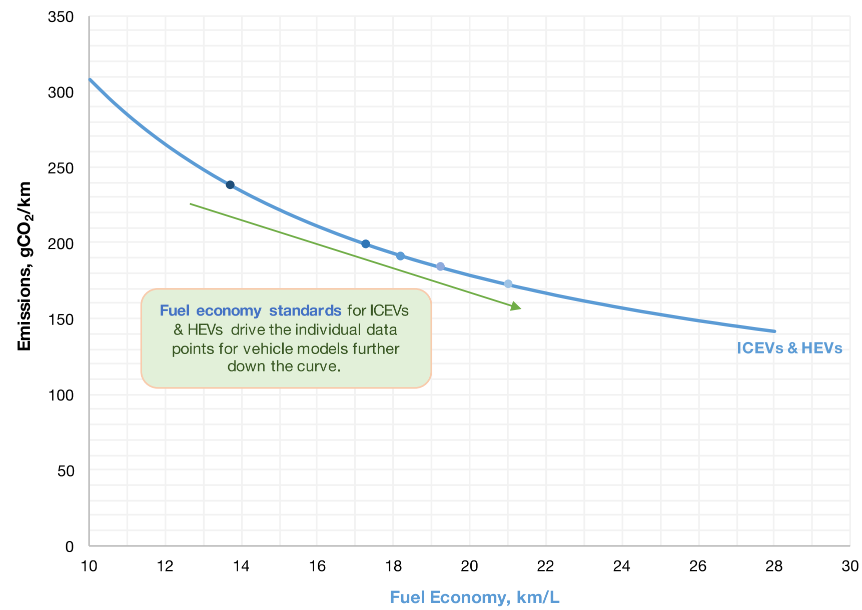

Figure 13: The Impact of Fuel Economy Standards on ICEVs and HEVs

Specific details of fuel economy standards suitable for new vehicles in Malaysia must be fleshed out through an analysis of technological capabilities of present-day ICEVs and HEVs, though there is little reason for local standards to fall far short of those implemented in other markets, particularly in Asia. Japanese manufacturers Honda, Nissan and Toyota, who control just under 36% of the local new vehicle market share[45], are already required to meet stringent emissions standards in their domestic markets. They should do so in Malaysia, too. This holds true for Korean and German carmakers as well; the onus to uphold Malaysian fuel economy standards, therefore, would fall on the local manufacturers, Perodua and Proton, to produce fuel-efficient vehicles. To an extent, they already do; nevertheless, much potential for improvement still remains, and the implementation of fuel economy standards can play a role in realising this.

[44] A discussion of the importance of improvements to the accessibility, reach, and use of public transport, on transport emissions at large, is beyond the scope of this particular analysis. Suffice it to say that per-kilometre emissions of shared public transport options are considerably lower than those of private alternatives. The potential scope of emissions reductions therefore increases with greater public transport usage.

[45] https://paultan.org/2018/01/23/vehicle-sales-performance-in-malaysia-2017-vs-2016-a-look-at-last-years-biggest-winners-and-losers/

5 Limitations and Areas for Future Research

Efforts have been made to include within this analysis any and every variable which may significantly affect the emissions intensities of ICEVs, HEVs, and EVs throughout their life-cycles, particularly those which might affect each technology disproportionately. However, not every factor can be accounted for. One such limitation was highlighted in Section 3b; it is impossible to predict with certainty the impacts of future developments in the fuel economies of ICEVs and HEVs relative to the electric efficiencies of EVs, though Figure 11 represented an attempt to account for that. In any case, it was postulated that this factor would most likely fortify further the dangers of vehicle fleet electrification. As a result, it has been assumed that the inclusion of such a variable would not have significantly altered the overarching takeaways of this analysis.

At the same time, there are two ways in which this study could be improved. First, the life-cycle emissions intensity of individual electricity generation sources may not accurately represent the actual emissions intensity of electricity sources in the Malaysian context; the IPCC data is the result of a review of the estimates then-currently available in the life-cycle analysis literature, which in turn analyses technologies in use across the world. To the author's knowledge, there is no verifiable source of information that covers the life-cycle emissions associated with electricity generation, by power plant, in Peninsular Malaysia *alone*. However, any disparities between the IPCC median estimates and the actual emissions levels of local power plants would only be meaningful in altering the results of this study *if* the life-cycle emissions of coal-powered electricity in Malaysia are: i) higher than those reported in the IPCC study, in which case the environmental effects of EVs would be worse than projected in Section 3, or ii) lower than those reported in the IPCC study, in which case EVs would match the emissions intensity of ICEVs at a higher GACI than projected in Section 3. Again, the conclusions that EVs are relatively more harmful than petrol-powered alternatives given the present electricity grid composition, and that it is likely the case that the 2025 renewables target would be insufficient in ensuring that EVs are cleaner than the alternatives, would not be impacted.

The second point of contention relates to the disparities typically observed between fuel economy ratings claimed by automakers and those revealed in real-world conditions. The European Federation for Transport and Environment estimates that, on average, petrol-powered vehicles' fuel economy ratings were overstated by 42% in 2015, with the differences in emissions between test- and real-world conditions having increased steadily for over a decade[46]. For HEVs, the disparity is estimated to be greater than for ICEVs, though this may be due to the relatively small sample size of HEV fuel economy estimates. Unfortunately, and crucially in the context of this study, there is a severe lack of research into any disparities that might exist between claimed and real-world efficiencies of EVs, in energy requirements per unit of distance. Yuksel and Michalek (2015) do identify a relationship between regional temperature and EV efficiency, finding that the energy efficiency of a Nissan Leaf peaks at roughly 18°C; at 30°C, efficiency is reduced by 20%[47]. It is possible, then, that electric efficiencies observed under test-conditions would not be matched by those achieved in real-world conditions. If the energy efficiency of EVs is overstated to a similar degree as that of ICEVs and HEVs, the results of this study will hold true; if the fuel economy gap of ICEVs and HEVs far outstrips the electric efficiency gap of EVs, it would not be possible to read too much into the specific grid-average carbon intensity points at which EVs are cleaner than petrol-powered engines. In any case, without the requisite research on energy efficiency gaps in EVs, it would be impossible to incorporate the necessary variables into the model outlined in Section 2. In any case, the current dangers of vehicle fleet electrification cannot be ignored.

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[46] European Federation for Transport and Environment (2016)
[47] Yuksel & Michalek (2015)

6 Concluding Remarks

Without question, electric vehicles have tremendous potential in reducing the greenhouse gas emissions attributable to private road transport. This potential can only be translated into reality, however, under certain conditions. The most important factor determining the environmental impact of EVs, relative to petrol-powered vehicles, is the carbon intensity of local electricity generation. In the context of Malaysia, where 57% of electricity is generated through the burning of coal, and a further 35% via natural gas, EVs are on average considerably more polluting than ICEVs and HEVs. This will still be the case should Malaysia reach its 2025 target of 20% renewable energy penetration; it is only as the electricity grid approaches a state of relative equivalence between coal, natural gas, and renewables that EVs represent an improvement, in the context of carbon emissions, over fuel-efficient petrol-powered vehicles.

For this reason, and due to a general need for effective climate action, it is imperative that the decarbonisation of Malaysia's electricity grid be considered a national priority over the coming decades. This would enable a long-term strategy of emissions reductions through vehicle fleet electrification, and provide policymakers with time to prepare the infrastructure necessary for such a transition. Malaysia must take a patient approach with EVs; this entails 'taking things slow' with a potential national electric car project. In the interim, the government should progress with other, less financially- and environmentally-costly policy options in the drive to mitigate emissions attributable to the transport sector. This study has highlighted two ways through which the incumbent Pakatan Harapan government could instead address the sustainability of private transport in Malaysia: i) a revamp of the energy efficient vehicle (EEV) policy, which at present is too lenient in its requirements, too broad in its scope, and too opaque in its incentivisation structure; and ii) the implementation of fuel economy standards, which will ensure steady increases in the energy efficiency ratings of ICEVs and HEVs.

At the same time, attention should be paid toward measures that improve the accessibility and reach, and increase the utilisation, of public transportation across the country. Buses and trains, for instance, are significantly less polluting, per passenger-kilometre, than all modes of private transport; to maximise the magnitude of emissions reductions from the transport sector at large, Malaysians must increasingly shift from using private vehicles, to public ones. This will not happen without further investment in public transport infrastructure across Malaysia. Crucially, this will also not happen if Malaysia prematurely rides on the electric vehicle bandwagon.

7 Appendix

7a Deriving Manufacturing Emissions for ICEVs and EVs at Varying GACIs

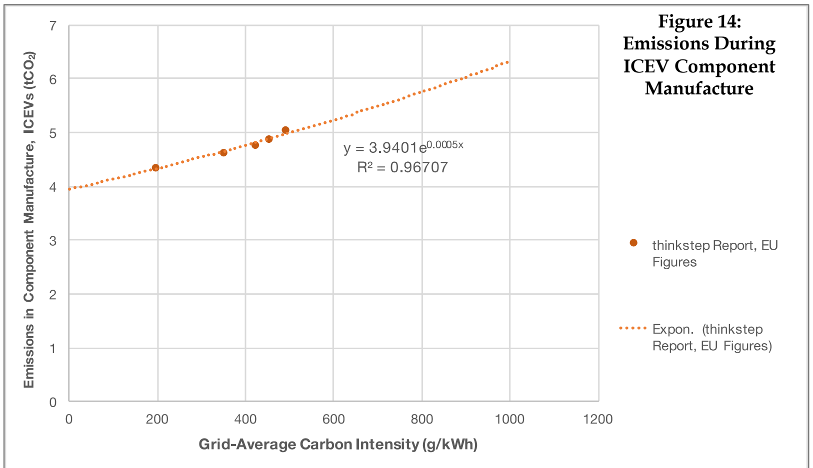

Figure 14: Emissions During ICEV Component Manufacture

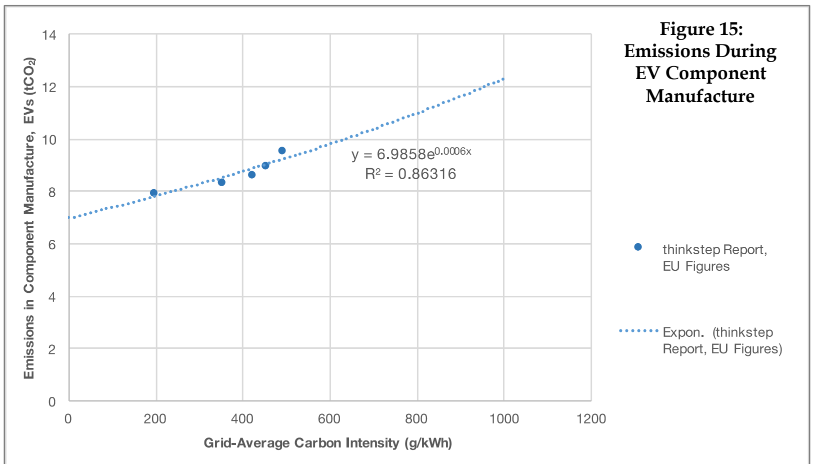

Figure 15: Emissions During EV Component Manufacture

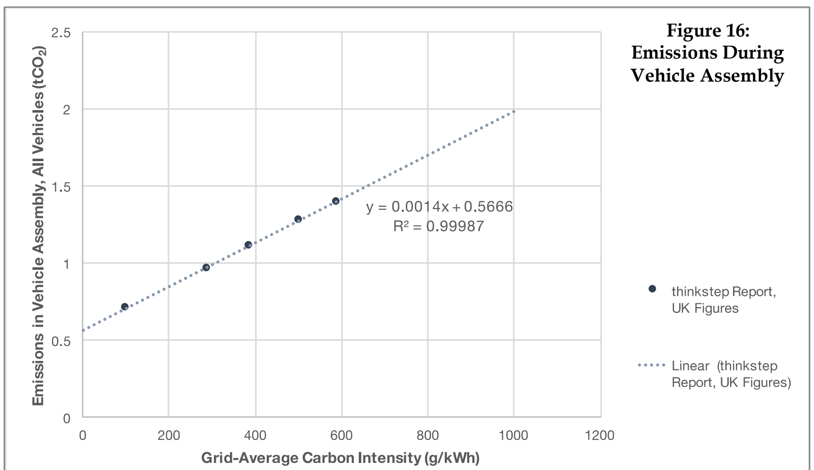

Figure 16: Emissions During Vehicle Assembly

7b Detailed Results: Per-Kilometre Emissions under Various Electricity Grid Compositions

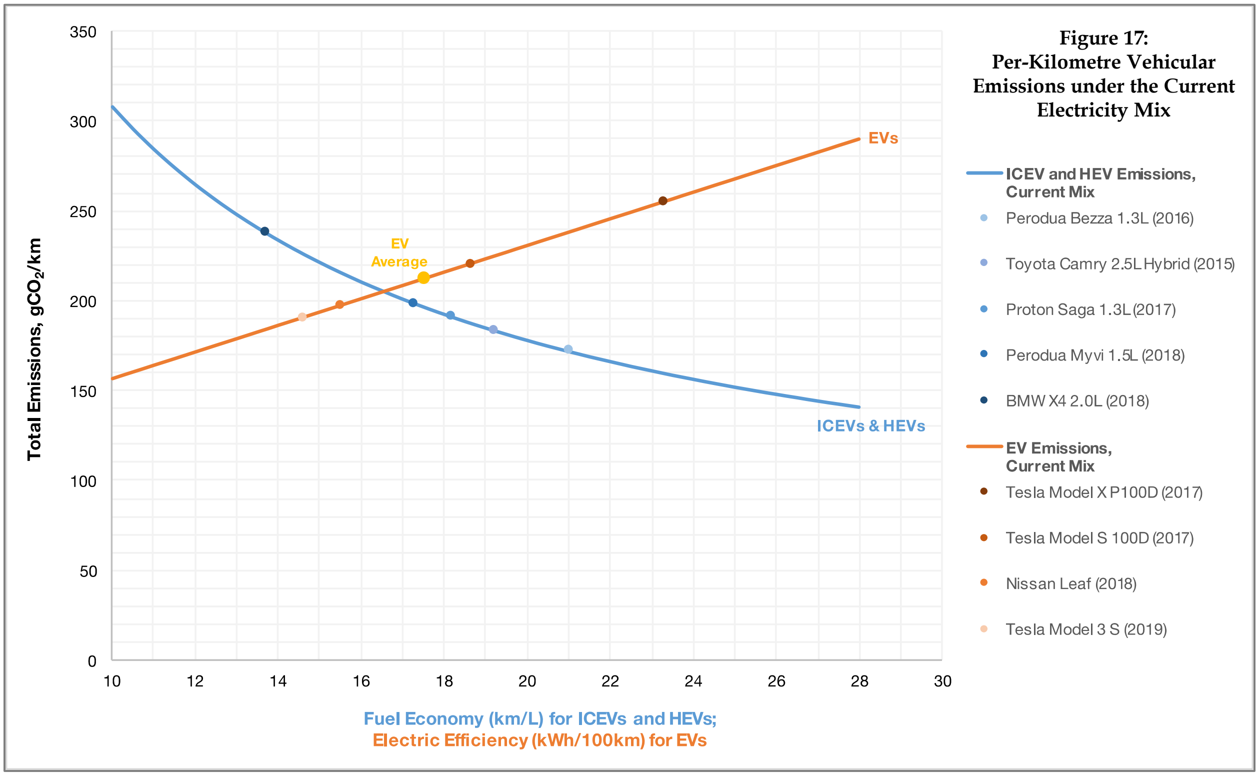

Figure 17: Per-Kilometre Vehicular Emissions under the Current Electricity Mix

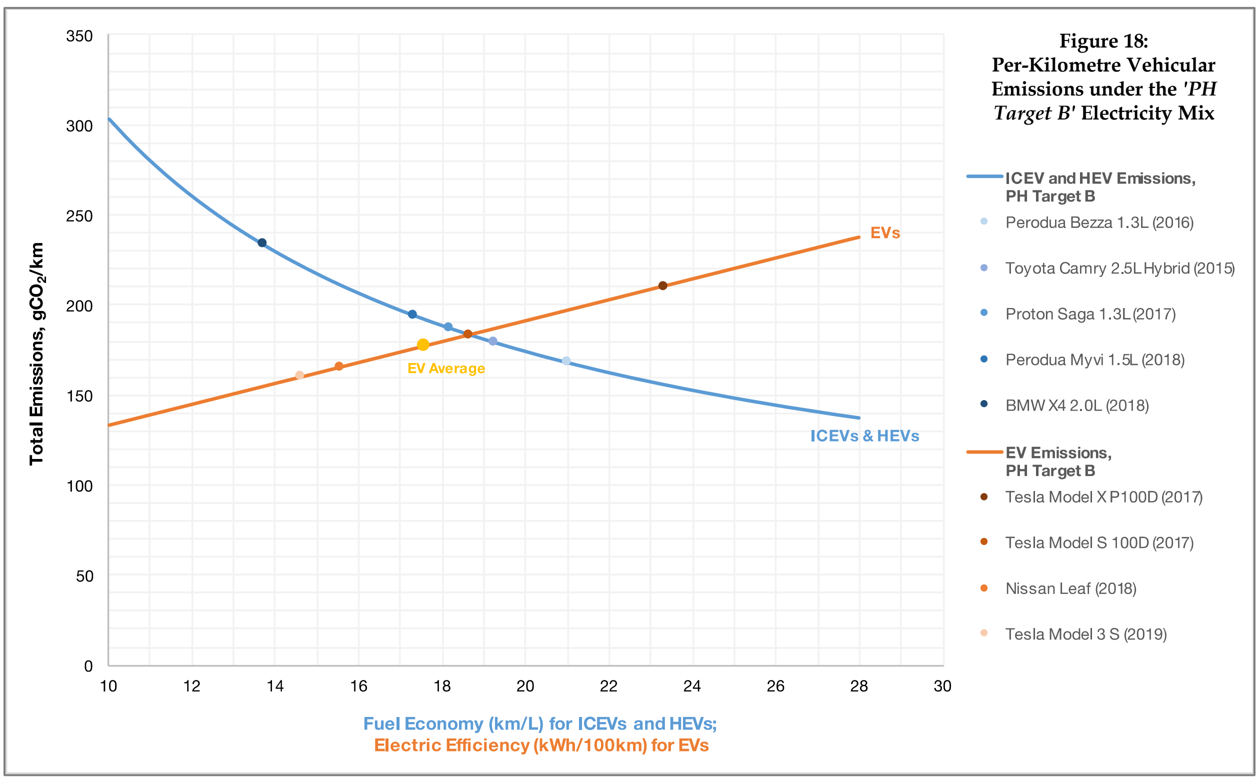

Figure 18: Per-Kilometre Vehicular Emissions under the *'PH Target B'* Electricity Mix

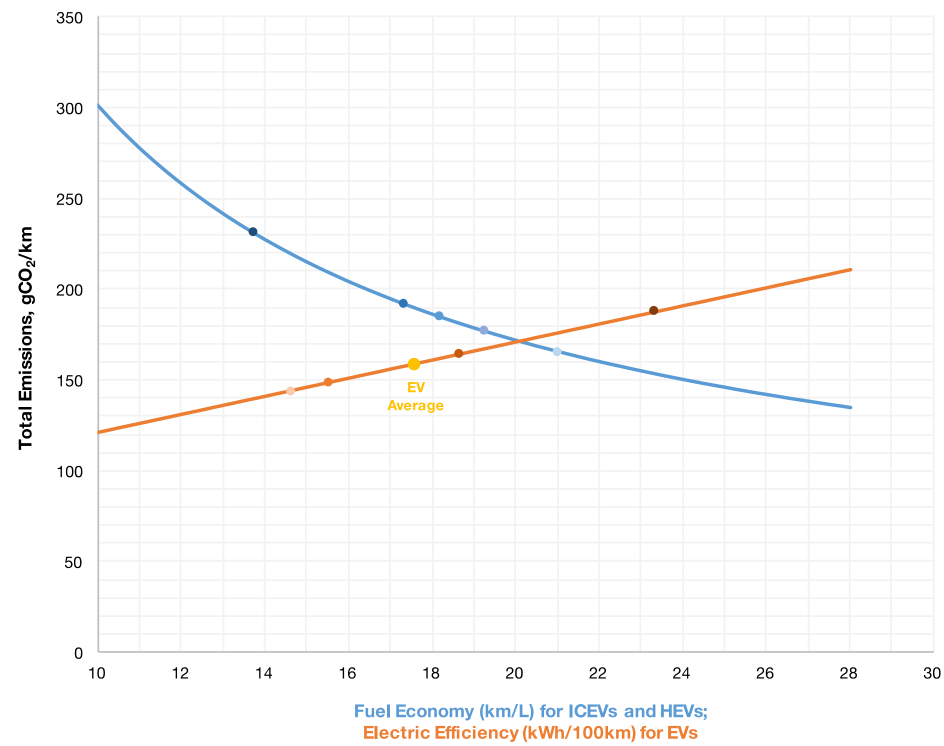

Figure 19:
Per-Kilometre Vehicular Emissions under the '*LR Equivalence*' Electricity Mix

These figures highlight the per-kilometre emissions of ICEVs and HEVs attaining a fuel economy within the range of 10 and 28*km/L*, and of EVs attaining an electric efficiency within the range of 10 and 28*kWh/100km*, across the various grid compositions of interest and importance in the context of Malaysia. Along the ICEVs & HEVs curves are plotted the per-kilometre emissions of the Peroduas Bezza and Myvi, Toyota Camry Hybrid, Proton Saga, and the BMW X4. For EVs, the models plotted are those studied in Sections 3a and 3b.

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