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Comment on "Consumer purchase intentions for electric vehicles: Is green more important than price and range?" K. Degirmenci, MH Breitner *Transportation Research Part D* 51 (2017) 250–260

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This recently published article about electric vehicles (EVs) is a reminder of the importance of well identified premises used in the design of research and the need for substantiated assertions.

My primary concern regards the statement contained in their Discussion p 255, "For example, in the United States a transition from combustion to EVs **would** in fact increase CO_2 emissions, because **half of the electricity is produced from coal**." (My emphases)

The authors use dated source material to back up this statement about electricity production in the United States of America (USA). The information source Degirmenci and Breitner (2017) used was Hasan and Dwyer (2010) who wrote "A transition in the US from gasoline to electric vehicles **could** increase CO_2 emissions, because half of US electricity is produced by coal", for which Hasan & Dwyer did not provide any reference.

The paper by Degirmenci and Breitner (2017) in my opinion falls short by not ascertaining this claim about US electricity generation. A quick internet search reveals more recent information on this matter. For example, the US Energy Information Administration (US EIA, 2017d) lists that in 2016, 30.4% of electricity in the USA was generated using coal. The Degirmenci and Breitner (2017) statement needs to be substantiated with recent, reliable sources given the very dynamic nature of electricity production. Historical data (US EIA, 2017a) reveals the changing nature of energy sources for electricity production in the US, for example the year before in 2015, 33% was generated from coal, demonstrating its decreasing role.

The authors' outdated information source allows a misleading interpretation of the resulting greenhouse gas (GHG) emissions from electricity consumed by EVs compared to the use of gasoline by Internal Combustion Engine Vehicles (ICEVs). Furthermore, the subtle change of qualification from "could" to a more definite "would" perhaps leads the reader to believe that making the transition from ICEVs to EVs definitely would increase CO_2 emissions in the USA. Degirmenci and Breitner (2017) fail to justify the assertion that a transition from gasoline to electricity **would** increase CO_2 emissions.

Conventional ICEVs have fixed emissions per kilometre, depending on the model, whereas BEV emissions are variable, depending on the electricity supply. Calculations (see Table 1) to compare ICEV emissions with BEV emissions can be made for cars used in countries with poor and good grid mixes. Ang and Su (2016) calculated the aggregated carbon intensity (ACI) of electricity production at the global and country level; while most countries decreased their ACI in the period 1990–2013, some increased. The grams of CO_2 emissions per kilometre of travel for BEVs can be calculated based on data from laboratory tests (US EPA, 2017) and the ACI of a particular country where a car is being driven. Improvements in thermal efficiency of electricity generation, switching to cleaner fossil fuels and reducing fossil fuel share reduce ACI values (Ang and Su, 2016); as ACI values become lower so too do the emissions from BEVs. Most countries use a mix of fuel sources to generate electricity; the share of coal is different for each country and in many is dropping, for example South Africa used 94% coal in 2012 (World Coal Association, 2016) whereas in the UK (UK DBEIS, 2017) coal use dropped to 9.3% in the 4th Quarter of 2016 (half of the previous year's share). Different states in the US have widely different grid mixes e.g. West Virginia in 2015 used 94% coal while California used 0.2% coal (US EIA, 2017c).

It can be demonstrated that for most countries using BEVs results in lower emissions per kilometre of travel than using ICEVs. The

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Table 1
Aggregated carbon intensity (ACI values) (Ang and Su, 2016) for electricity production in select countries (including five most intense) and vehicle emissions per kilometre travel.

Country	ACI 2013 (kg CO_2 /kWh)	Model of car	EVs Published[a] Fuel Economy kWh/km [kWh/100 miles]	ICEV Published[a] fuel consumption (combined) L/100 km [US gall/100 miles]	Vehicle Emissions g CO_2 /km
ICEV examples					
USA models		2016 VW Golf 1.8 L automatic turbo (gasoline)		8.0 [3.4]	187.9
		2016 BMW 328 d 2 L turbo (diesel)		6.8 [2.9]	210.3
		2013 VW Golf 2.5 L automatic (gasoline)		8.9 [3.8]	209.1
EV examples					
Iraq[b]	1.0151	2016 VW e Golf	0.18 [29 kWh/100 mile]		182.7
		2016 Tesla Model S AWD 85D	0.21 [34 kWh/100 mile]		213.2
South Africa	0.9333	2016 VW e Golf	0.18		168
		2016 Tesla Model S AWD 85D	0.21		196
Poland	0.8135	2016 VW e Golf	0.18		146.4
		2016 Tesla Model S AWD 85 D	0.21		170.8
India	0.7927	2016 VW e Golf	0.18		142.7
		2016 Tesla Model S AWD 85D	0.21		166.5
Australia	0.7806	2016 VW e Golf	0.18		140.5
		2016 Tesla Model S AWD 85 D	0.21		163.9
China	0.6916	2016 VW e Golf	0.18		124.5
		2016 Tesla Model S AWD 85D	0.21		145.2
United States	0.4858	2016 VW e Golf	0.18		87.4
	0.4858	2016 Tesla Model S AWD 85 D	0.21		102.0
Germany	0.4639	2016 VW e Golf	0.18		83.5
		2016 Tesla Model S AWD 85 D	0.21		97.4
United Kingdom	0.4382	2016 VW e Golf	0.18		78.9
		2016 Tesla Model S AWD 85D	0.21		92.0
France	0.0550	2016 VW e Golf	0.18		9.9
		2016 Tesla Model S AWD 85D	0.21		11.6
Sweden	0.0144	2016 VW e Golf	0.18		2.6
		2016 Tesla Model S AWD 85D	0.21		3.0

Notes for the table:
Conversion rates:
1 mile = 1.61 km.
1 US liquid gallon = 3.785 L.
1 lb = 453.59 g.
1 US gallon of gasoline (no ethanol) produces 19.6 lb CO_2 (or 8890.41 g CO_2/gallon = 2349 g CO_2/L gasoline) (US EIA, 2017b).
1 US gallon of diesel produces 22.4 lb CO_2 (or 10160.47 g CO_2/gallon = 3092.61 g/L diesel) (US EIA, 2017b).

[a] US EPA (2017).
[b] Iraq's ACI in 1990 was 0.5512 but subsequent wars have seen a dramatic change in its ACI.

following formulae, using data provided from the US Environment Protection Agency (EPA) (US EPA, 2017) and 2013 ACI values for particular countries (Ang and Su, 2016), were used to calculate emissions per kilometre for ICEVs and BEVs. Popular models of vehicles available in 2013 and 2016 were selected; these readily accessible and consistent figures could be used to calculate emissions /km for any model of vehicle published on the EPA's fuel economy website (US EPA, 2017). While it is recognised that manufacturers produce models specific to individual markets, and that as newer models are developed emissions may decrease, Table 1 gives an indication of the efficacy of EVs compared to ICEVs.

EV Formula: $ACI\ \ emissions \times EV\ \ consumption \times 1000 = \text{g CO}_2/\text{km}$

(units) $\frac{\text{kg CO}_2}{\text{kWh}} \times \frac{\text{kWh}}{\text{km}} \times \frac{\text{g}}{\text{kg}} = \text{g CO}_2/\text{km}$

ICEV Formula: $ICEV\ \ emissions \times ICEV\ \ consumption \times 100 = \text{g CO}_2/\text{km}$

(units) $\frac{\text{g CO}_2}{\text{L}} \times \frac{L}{100\text{ km}} \times 100 = \text{g CO}_2/\text{km}$

The examples used in Table 1 demonstrate that even in the five countries with the highest carbon intensity for their electricity production (Iraq, South Africa, Poland, India, Australia), the smaller BEV selected had lower emissions per kilometre than the ICEVs selected. Only in Iraq and South Africa did the larger more powerful Tesla have slightly higher emissions than at least one of the smaller ICEVs selected. For all other countries, which have lower ACI values, these BEVs produced fewer emissions than these ICEVs.

However, it should be noted that Tietge et al. (2016) have compared real world data with type approval values for car emissions and found increasing divergence. They showed, based on European Environment Agency data, type approval values (EU averages) for ICEV CO_2 emissions went from 170 g/km in 2001 to 120 g/km in 2015, a decrease of 30%. However, their evidence (n = 134,000) indicates there is an increasing divergence between laboratory results and real world performance of new cars: real world data (EU averages) suggests that new European cars actually went from 183 g CO_2/km in 2001 to 167 g CO_2/km in 2015, a decrease of less than 10%. If this assertion is applied it may be expected that the benefits of using BEVs are even higher than demonstrated above.

Further to the above arguments, different countries would achieve different total emissions from their fleets depending on a number of factors including: the numbers of vehicles, the types of vehicles favoured by drivers and the design rules. For example, in Australia in 2013, the national average carbon emissions from new passenger cars and light commercial vehicles was 192 g CO_2 /km, ranging from 144 g CO_2 /km for the smallest passenger vehicles to the highest of 288 g CO_2 /km for the largest SUVs (National Transport Commission, 2014).

Additional evidence to rebut the authors' assertion can be applied from a number of sources:

1. Renault (2011) conducted a Life Cycle Analysis (LCA), for company purposes, of its *Fluence* vehicle in its two motorisations – the ICEV (in both forms – petrol and diesel) and fully electric vehicle (BEV). Calculations for electricity used British and French data separately. While production of EVs results in higher GHG emissions than ICEVs due to the batteries, operationally the BEV outperformed the ICEVs, even with the grid mix of that time, due to BEVs' global efficiency and lower primary energy needs for driving (Renault, 2011). Including production inputs, when using French electricity the *Fluence* EV had lower total GHG emissions compared to the *Fluence* ICEVs after only about 2 years average use, whereas using British electricity it was after about 4 years (Renault, 2011). As a country's electricity transitions to renewables, these results should improve.
2. Hawkins et al. (2012) conducted LCAs and calculated that if a BEV was driven, using average European electricity for 150,000 km, emissions were reduced by 10% compared to diesel vehicles, and a 24% improvement over petrol vehicles. However, they noted other aspects of EVs supply chain resulted in other forms of pollution. Improvements in battery technology, production and recycling techniques may reduce such pollutants.
3. Furthermore, research into the potential of EVs used for personal travel to meet current USA policy targets for transport emissions reductions of 26–28% of 2005 levels by 2025, determined that EV models available in 2013, even with the prevailing US electric grid mix, were capable of meeting the target (Needell et al., 2016), although to meet higher targets electricity sources would need to decarbonise. Those US states with relatively low coal use for electricity production should have higher emissions reduction than these averages.

In summary, while in other fields using older data may be acceptable, the fields of electricity production and EVs are dynamic and caution should be exercised when relying on such material in modern research. I am concerned that Degirmenci and Breitner (2017), by inadequate attention to sources of information, are perpetuating out of date notions about the usefulness of electric vehicles in mitigating GHG emissions from motorised personal transport.

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