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Fuel Sources for Electricity in the Individual Countries of the World and the Consequent Emissions from Driving Electric Vehicles

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FUEL SOURCES FOR ELECTRICITY IN THE INDIVIDUAL COUNTRIES OF THE WORLD AND THE CONSEQUENT EMISSIONS FROM DRIVING ELECTRIC VEHICLES

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16. Abstract

This study was designed to evaluate the relative amounts of greenhouse-gas emissions from driving a battery-electric vehicle (BEV) compared with greenhouse-gas emissions from driving a traditional gasoline-powered vehicle in different countries of the world. The reasons for conducting such a country-by-country comparison are that (1) the indirect emissions from BEVs depend on the mix of fuel sources used to generate electricity, and (2) countries differ widely in their fuel-source mix. (Emissions associated with manufacturing each vehicle type were not considered in this analysis.)

The analysis used two key sets of data: (1) BEV miles-per-gallon-equivalent values based on well-to-wheels emissions of various electricity fuel sources calculated by the Union of Concerned Scientists, and (2) country-specific electricity production by fuel source compiled by the International Energy Agency. Specifically, for each individual country, the calculations derived an equivalent fuel-economy value at which both BEVs and gasoline-powered vehicles produce the same amount of greenhouse-gas emissions. In other words, the calculations derived, for each country, a fuel-economy value that a gasoline-powered vehicle would have to exceed to produce lower emissions than a typical BEV, and vice versa.

The calculated fuel-economy-equivalent values for individual countries vary greatly, depending on the mix of fuels used to generate electricity within each country. On one extreme is Albania (which generates 100% of its electricity from hydroelectric power) with 5,100.0 MPG_{ghg} (0.05 L/100 km); on the other extreme are Botswana and Gibraltar (which generate 100% of their electricity from coal and oil), each with 29.0 MPG_{ghg} (8.1 L/100 km). The corresponding value for the United States is 55.4 MPG_{ghg} (4.2 L/100 km), while the average for the world is 51.5 MPG_{ghg} (4.6 L/100 km). The values for all 143 examined countries are presented in tabular form, as well as in a color-coded world map.

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Introduction

This study was designed to evaluate the relative amounts of greenhouse-gas emissions from driving a battery-electric vehicle (BEV)[1] compared with greenhouse-gas emissions from driving a traditional gasoline-powered vehicle in different countries of the world. The two reasons for conducting such a country-by-country comparison are that (1) the indirect emissions from BEVs depend on the mix of fuel source used to generate electricity, and (2) countries differ widely in their fuel-source mix.

The analysis used two key sets of data: (1) well-to-wheels BEV miles-per-gallon-equivalent values by electricity fuel source derived by the Union of Concerned Scientists, and (2) country-specific electricity production by fuel source compiled by the International Energy Agency.

Background

Well-to-wheels BEV miles-per-gallon-equivalent values by electricity fuel source

A recent study by the Union of Concerned Scientists (Nealer, Reichmuth, and Anair, 2015) presented a comprehensive "well-to-wheels" analysis of the greenhouse-gas emissions from driving BEVs compared with those from gasoline-powered vehicles. For BEVs, this analysis included (1) emissions from extracting and delivering raw materials to the electric power plants, (2) emissions generated by using the specific fuel in the process of producing electricity, (3) electricity losses during electricity distribution, and (4) the fuel efficiency of the vehicle.

For a gasoline-powered vehicle, the UCS analysis included emissions from (1) extracting crude oil, (2) transporting the oil, (3) refining the oil into gasoline, (4) delivering the gasoline to a retail outlet, and (5) combusting the gasoline in the vehicle.

The UCS analysis derived, for each electricity fuel source, a gasoline miles-per-gallon equivalent in terms of greenhouse-gas emissions—MPG_{ghg}. "If an electric vehicle has an MPG_{ghg} value equal to the MPG of a gasoline-powered vehicle, both vehicles will

[1] While battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are both considered to be electric vehicles, only BEVs were included in this analysis due to their exclusive use of electricity as a fuel source (vs. PHEVs that can use both electricity and gasoline).

produce the same amount of global warming emissions for each mile traveled" (Nealer, Reichmuth, and Anair, 2015, p. 7). It follows that a gasoline-powered vehicle would produce lower well-to-wheels emissions only if its MPG value is higher than the MPG_{ghg} value for a BEV.[2]

The UCS conclusions concerning BEV MPG_{ghg} by fuel source used to generate electricity are presented in Table 1 (Nealer, Reichmuth, and Anair, 2015), and these values were used in the calculations in the present analysis.

Table 1
Fuel-economy equivalent of battery-electric vehicles by fuel source for electricity (Nealer, Reichmuth, and Anair, 2015).

Energy source	Fuel-economy equivalent (MPG_{ghg})
Coal	29
Oil	29
Natural gas	58
Geothermal	310
Solar	350
Nuclear	2,300
Wind	2,500
Hydro	5,100

Electricity production by fuel source in individual countries

IEA (2017) presents a tabulation of electricity production by fuel source for individual countries of the world. The data are applicable for 2015. The fuel-source categories in the IEA data were the eight sources used in the UCS analysis (coal, oil, natural gas,[3] geothermal, solar,[4] nuclear, wind, and hydro), plus biofuels, waste, tide, and other sources. Because the UCS analysis (Nealer, Reichmuth, and Anair, 2015) does not

[2] For gasoline-powered vehicles, the MPG value being compared corresponds to the combined city/highway window-sticker fuel-economy value.

[3] The IEA entry is labeled as "gas."

[4] The IEA database includes separate entries for *solar thermal* and *solar photovoltaic (PV)*. The values for these two entries were combined because the UCS analysis (Nealer, Reichmuth, and Anair, 2015) includes an MPG-equivalent value only for the general category of *solar*.

include data for biofuels, waste, tide, and other sources, the electricity generated from these fuel sources was excluded from the present analysis.

The IEA data used in this analysis were available for 143 out of 195 currently recognized sovereign states (i.e., countries) in the world today (U.S. Dept. of State, 2017). Those countries lacking data were predominantly located in Africa and the island nations of the Caribbean and South Pacific regions.

Method

The analysis in this study involved calculating an average MPG_{ghg} value for BEVs for each individual country included in the IEA database, by weighting the fuel-economy equivalents in Table 1 for different fuel sources derived by UCS (Nealer, Reichmuth, and Anair, 2015) by the respective distributions of fuel sources to generate electricity in each country (IEA, 2017). Because of the non-linear relationship between miles per gallon and fuel consumed per distance driven (Larrick and Soll, 2008), the weighting calculations were performed in units of gallons per mile, with the final results converted back into miles per gallon.

Results

Table 2 lists the fuel-economy-equivalent values for BEVs for each country. Table 2 is divided into four groups and is color-coded using the following ranges of MPG_{ghg} values:

- greater than 1000 (11 countries)
- between 100 and 1000 (26 countries)
- between 52 (the average for the world is 51.5) and 99 (54 countries)
- between 29 and 51 (52 countries)

Figure 1 presents a map of the world with the data from Table 2, using the same groupings and color-coding scheme.

The fuel-economy-equivalent values range from 5,100.0 MPG_{ghg} for Albania (which generates 100% of its electricity from hydroelectric power) to 29.0 MPG_{ghg} for both Botswana (which generates 100% of its electricity from coal and oil[5]) and Gibraltar (which generates 100% of its electricity from oil). The value for the United States is 55.4 MPG_{ghg}.

The appendix lists the fuel-economy-equivalent values (MPG_{ghg}) for each individual country, sorted alphabetically by country.

[5] Botswana obtains 0.03% if its electricity from solar energy.

Table 2
MPG-equivalent values (MPG_{ghg}) for BEVs for individual countries. Also shown are the corresponding liters per 100 km (i.e., fuel consumption).

Group	Country	MPG-equivalent	L/100 km
1000 – 5100 MPG_{ghg}	Albania	5100.0	0.05
	Paraguay	5084.1	0.05
	Nepal	5071.3	0.05
	Ethiopia	4463.3	0.05
	Congo (Dem. Rep.)	4003.6	0.06
	Switzerland	1905.3	0.1
	Norway	1820.6	0.1
	Sweden	1421.6	0.2
	Tajikistan	1389.8	0.2
	Namibia	1047.1	0.2
	Costa Rica	1044.3	0.2
100 – 999 MPG_{ghg}	Iceland	990.3	0.2
	Zambia	815.1	0.3
	France	524.6	0.4
	Mozambique	378.2	0.6
	Georgia	253.8	0.9
	Uruguay	210.4	1.1
	New Zealand	203.0	1.2
	Kyrgyzstan	198.0	1.2
	Luxembourg	171.1	1.4
	Austria	170.9	1.4
	Canada	169.5	1.4
	Kenya	167.9	1.4
	Armenia	156.2	1.5
	Brazil	155.9	1.5
	Slovak Republic	152.5	1.5
	Finland	136.5	1.7
	Cameroon	134.5	1.7
	Myanmar	132.0	1.8
	Columbia	125.0	1.9
	Congo	122.7	1.9
	Peru	113.4	2.1
	Belgium	111.3	2.1
	Togo	108.5	2.2
	Venezuela	107.6	2.2
	Korea-North	105.0	2.2
	Croatia	101.5	2.3
52 – 99 MPG_{ghg}	Latvia	99.3	2.4
	Ghana	96.7	2.4
	Lithuania	93.8	2.5
	Hungary	92.6	2.5
	Slovenia	91.1	2.6
	Gabon	86.2	2.7
	Panama	82.4	2.9
	Denmark	81.5	2.9
	Sudan	80.9	2.9
	Spain	80.5	2.9

(continued)

Table 2 (continued)

Group	Country	MPG-equivalent	L/100 km
52 – 99 MPG_{ghg} (continued)	Romania	79.9	2.9
	Bolivia	79.6	3.0
	Ukraine	75.0	3.1
	Suriname	72.0	3.3
	Nigeria	70.7	3.3
	Russian Federation	70.7	3.3
	Ecuador	69.3	3.4
	Uzbekistan	69.1	3.4
	United Kingdom	67.8	3.5
	Argentina	67.6	3.5
	Portugal	65.8	3.6
	Tanzania	65.5	3.6
	Cote d'Ivoire	64.6	3.6
	Italy	64.5	3.6
	Viet Nam	61.8	3.8
	Angola	61.5	3.8
	Moldova	61.0	3.9
	Zimbabwe	60.2	3.9
	Bulgaria	59.1	4.0
	El Salvador	58.7	4.0
	Turkey	58.5	4.0
	Azerbaijan	58.0	4.1
	Bahrain	58.0	4.1
	Qatar	58.0	4.1
	Turkmenistan	58.0	4.1
	Trinidad and Tobago	57.9	4.1
	Belarus	57.6	4.1
	Pakistan	57.5	4.1
	Algeria	57.4	4.1
	Brunei Darussalam	57.4	4.1
	Ireland	57.4	4.1
	United Arab Emirates	57.4	4.1
	Montenegro	57.3	4.1
	Guatemala	57.2	4.1
	Singapore	57.0	4.1
	Tunisia	56.9	4.1
	Oman	56.5	4.2
	Mexico	56.2	4.2
	Sri Lanka	55.7	4.2
	United States	55.4	4.2
	Chile	54.5	4.3
	Cambodia	53.4	4.4
	Iran	53.4	4.4
	Germany	52.1	4.5
	WORLD	***51.5***	***4.6***
29 – 51 MPG_{ghg}	Egypt	51.4	4.6
	Korea-South	50.7	4.6
	Nicaragua	50.6	4.6
	Czech Republic	50.2	4.7
	Thailand	49.6	4.7

(continued)

Table 2 (continued)

Group	Country	MPG-equivalent	L/100 km
29 – 51 MPG_{ghg} (continued)	Bangladesh	49.6	4.7
	Macedonia	46.1	5.1
	Greece	45.7	5.1
	Honduras	45.7	5.1
	Syria	45.7	5.1
	Bosnia and Herzegovina	44.9	5.2
	Philippines	44.8	5.3
	Netherlands	44.4	5.3
	Japan	44.3	5.3
	Taipei-China	43.3	5.4
	Malaysia	43.2	5.4
	Serbia	40.5	5.8
	Saudi Arabia	40.2	5.9
	China	40.0	5.9
	Israel	40.0	5.9
	Libya	39.6	5.9
	Morocco	39.0	6.0
	Jordan	38.7	6.1
	Australia	37.5	6.3
	Dominican Republic	37.4	6.3
	Indonesia	37.4	6.3
	Yemen	36.2	6.5
	India	35.7	6.6
	Kuwait	35.5	6.6
	Kazakhstan	35.4	6.6
	Hong Kong	34.9	6.7
	Iraq	34.5	6.8
	Senegal	32.6	7.2
	Poland	32.4	7.3
	Cuba	31.5	7.5
	Estonia	31.5	7.5
	Haiti	31.5	7.5
	South Africa	31.5	7.5
	Cyprus	31.3	7.5
	Jamaica	31.0	7.6
	Malta	31.0	7.6
	Mauritius	30.9	7.6
	Benin	30.7	7.7
	Curacao	30.1	7.8
	Mongolia	29.9	7.9
	Lebanon	29.8	7.9
	Kosovo	29.7	7.9
	Niger	29.2	8.1
	South Sudan	29.2	8.1
	Eritrea	29.1	8.1
	Botswana	29.0	8.1
	Gibraltar	29.0	8.1

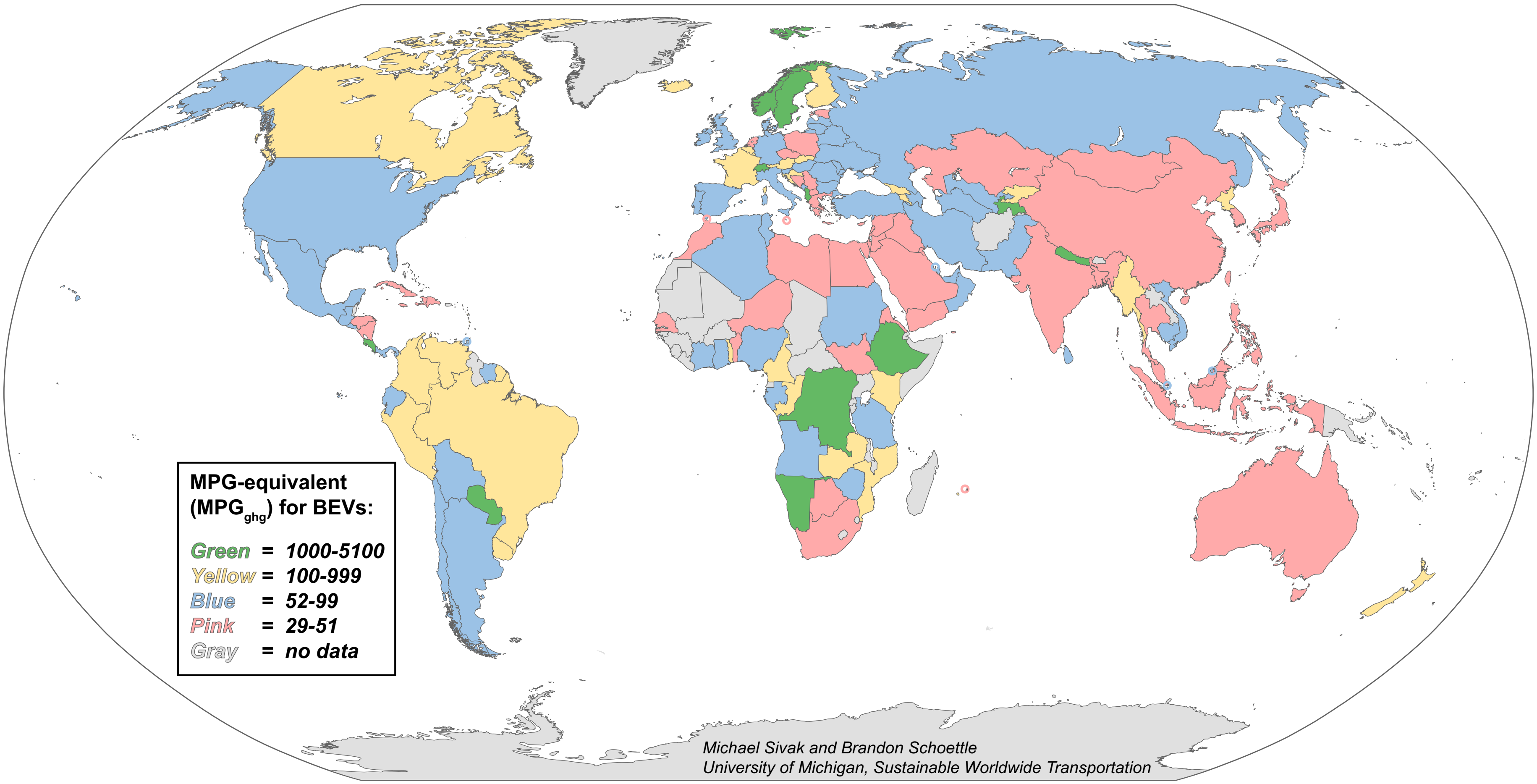

Figure 1. Color-coded world map of MPG-equivalent values (MPG$_{ghg}$) for BEVs.

Discussion

Comparison of BEVs with gasoline-powered vehicles

The present analysis indicates that, given the average mix of fuel sources for generating electricity in the world, a gasoline-powered vehicle would have to have fuel economy higher than 51.5 MPG (4.6 L/100 km) to produce lower emissions than an average BEV.

The corresponding equivalent-fuel-economy values for individual countries vary greatly, depending on the mix of fuels used to generate electricity within each country. On one extreme is Albania with 5,100.0 MPG_{ghg} (0.05 L/100 km); on the other extreme are Botswana and Gibraltar, each with 29.0 MPG_{ghg} (8.1 L/100 km). The corresponding values for the 12 countries with the largest economies (World Bank, 2017) are listed in Table 3.

Table 3
Fuel economy (and corresponding fuel consumption) required of a gasoline-powered vehicle to match the well-to-wheels emissions of an average BEV in the 12 countries with the largest economies.
(Countries are sorted in descending order by economy size.)

Country	MPG	L/100 km
United States	55.4	4.2
China	40.0	5.9
Japan	44.3	5.3
Germany	52.1	4.5
United Kingdom	67.8	3.5
France	524.6	0.4
India	35.7	6.6
Italy	64.5	3.6
Brazil	155.9	1.5
Canada	169.5	1.4
Korea-South	50.7	4.6
Russian Federation	70.7	3.3

Fuel sources for electricity not included in the analysis

Because the UCS analysis (Nealer, Reichmuth, and Anair, 2015) does not include emissions data for biofuels, waste-to-energy, tidal power, and other sources, the electricity generated from these fuel sources was excluded from the present analysis. For the world, the electricity generated by the excluded fuel sources accounted for 2.3% of all electricity. This percentage exceeded 10% for only 8 countries, with a maximum of 20.8% for Guatemala. For 19 countries, this value was greater than 5%, but smaller than 10%. For the remaining 116 countries, this value was less than 5%. Therefore, for the vast majority of countries, the excluded fuels are not likely to have a substantial influence on the results.[6]

Solar thermal and solar photovoltaic technologies

Solar thermal technology collects sunlight to generate heat that is then used to generate electricity (for example, with a steam-powered turbine). In contrast, solar photovoltaic technology directly converts the sunlight (i.e., photons) into electricity. The IEA data differentiate between the two technologies, but the UCS data does not, and includes information for the general category of "solar" only. Therefore, the present analysis combined the data for the two solar entries in IEA.

Energy efficiency of BEVs

The UCS calculations were based on the sales-weighted average electric efficiency of all electric-vehicle types in the United States for model year 2014 (i.e., both BEV and PHEV) of 0.33 kWh/mile (or 102 MPGe). To the extent that the average electric vehicle efficiency has improved since 2014, the calculations presented in this report are conservative.

Domestically produced versus imported electricity

The analysis considered only domestically generated electricity. Imported electricity was not taken into account.

[6] While biofuels—the largest group of the excluded fuel sources—are frequently treated as being inherently carbon neutral, there are some opposing views on this matter (e.g., DeCicco et al., 2016).

Worldwide applicability of the U.S. data

The present analysis relied, in part, on the well-to-wheels electricity equivalents for different fuel sources that were derived by UCS (Nealer, Reichmuth, and Anair, 2015) for typical electricity generation in the United States. Overall well-to-wheels emissions for gasoline-powered vehicles and for generating electricity from a specific fuel source (e.g., coal, natural gas, hydro, etc.) may be different for other countries; no attempt was made to tailor the calculations to specific conditions in each examined country.

Emissions from vehicle manufacturing

The present calculations were performed to evaluate the relative emissions from *driving* a BEV compared with *driving* a gasoline-powered vehicle. Emission differences from *manufacturing* the two different types of vehicles were not considered. The differences are due mostly to the additional emissions from manufacturing the large battery packs required by BEVs (Nealer, Reichmuth, and Anair, 2015).

UCS estimates that manufacturing a midsized BEV results in 15% higher emissions than manufacturing a comparably sized gasoline-powered vehicle (Nealer, Reichmuth, and Anair, 2015). For full-size vehicles, due to larger battery packs, the difference is greater—68% (Nealer, Reichmuth, and Anair, 2015). Currently, in the United States, UCS estimates that manufacturing a BEV results in about a third of its lifetime greenhouse-gas emissions, with the remaining two thirds of the lifetime emissions due to driving it.

Because emissions from vehicle manufacturing were not included in the present analysis, the calculations do not provide a complete comparison of lifetime (i.e., cradle-to-grave) greenhouse-gas emissions, only a comparison of direct and indirect emissions from the on-road operation of the vehicles (i.e., well-to-wheels).

Summary

This study was designed to evaluate the relative amounts of greenhouse-gas emissions from driving a battery-electric vehicle (BEV) compared with greenhouse-gas emissions from driving a traditional gasoline-powered vehicle in different countries of the world. The reasons for conducting such a country-by-country comparison are that (1) the indirect emissions from BEVs depend on the mix of fuel sources used to generate electricity, and (2) countries differ widely in their fuel-source mix. (Emissions associated with manufacturing each vehicle type were not considered in this analysis.)

The analysis used two key sets of data: (1) BEV miles-per-gallon-equivalent values based on well-to-wheels emissions of various electricity fuel sources calculated by the Union of Concerned Scientists, and (2) country-specific electricity production by fuel source compiled by the International Energy Agency. Specifically, for each individual country, the calculations derived an equivalent fuel-economy value at which both BEVs and gasoline-powered vehicles produce the same amount of greenhouse-gas emissions. In other words, the calculations derived, for each country, a fuel-economy value that a gasoline-powered vehicle would have to exceed to produce lower emissions than a typical BEV, and vice versa.

The calculated fuel-economy-equivalent values for individual countries vary greatly, depending on the mix of fuels used to generate electricity within each country. On one extreme is Albania (which generates 100% of its electricity from hydroelectric power) with 5,100.0 MPG_{ghg} (0.05 L/100 km); on the other extreme are Botswana and Gibraltar (which generate 100% of their electricity from coal and oil), each with 29.0 MPG_{ghg} (8.1 L/100 km). The corresponding value for the United States is 55.4 MPG_{ghg} (4.2 L/100 km), while the average for the world is 51.5 MPG_{ghg} (4.6 L/100 km). The values for all 143 examined countries are presented in tabular form, as well as in a color-coded world map.

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Appendix

Country	MPG-equivalent	L/100 km
WORLD	***51.5***	***4.6***
Albania	5100.0	0.05
Algeria	57.4	4.1
Angola	61.5	3.8
Argentina	67.6	3.5
Armenia	156.2	1.5
Australia	37.5	6.3
Austria	170.9	1.4
Azerbaijan	58.0	4.1
Bahrain	58.0	4.1
Bangladesh	49.6	4.7
Belarus	57.6	4.1
Belgium	111.3	2.1
Benin	30.7	7.7
Bolivia	79.6	3.0
Bosnia and Herzegovina	44.9	5.2
Botswana	29.0	8.1
Brazil	155.9	1.5
Brunei Darussalam	57.4	4.1
Bulgaria	59.1	4.0
Cambodia	53.4	4.4
Cameroon	134.5	1.7
Canada	169.5	1.4
Chile	54.5	4.3
China	40.0	5.9
Columbia	125.0	1.9
Congo	122.7	1.9
Congo (Dem. Rep.)	4003.6	0.06
Costa Rica	1044.3	0.2
Cote d'Ivoire	64.6	3.6
Croatia	101.5	2.3
Cuba	31.5	7.5
Curacao	30.1	7.8
Cyprus	31.3	7.5
Czech Republic	50.2	4.7
Denmark	81.5	2.9
Dominican Republic	37.4	6.3
Ecuador	69.3	3.4
Egypt	51.4	4.6
El Salvador	58.7	4.0
Eritrea	29.1	8.1
Estonia	31.5	7.5
Ethiopia	4463.3	0.05
Finland	136.5	1.7
France	524.6	0.4
Gabon	86.2	2.7
Georgia	253.8	0.9
Germany	52.1	4.5
Ghana	96.7	2.4

(continued)

Appendix (continued)

Country	MPG-equivalent	L/100 km
Gibraltar	29.0	8.1
Greece	45.7	5.1
Guatemala	57.2	4.1
Haiti	31.5	7.5
Honduras	45.7	5.1
Hong Kong	34.9	6.7
Hungary	92.6	2.5
Iceland	990.3	0.2
India	35.7	6.6
Indonesia	37.4	6.3
Iran	53.4	4.4
Iraq	34.5	6.8
Ireland	57.4	4.1
Israel	40.0	5.9
Italy	64.5	3.6
Jamaica	31.0	7.6
Japan	44.3	5.3
Jordan	38.7	6.1
Kazakhstan	35.4	6.6
Kenya	167.9	1.4
Korea-North	105.0	2.2
Korea-South	50.7	4.6
Kosovo	29.7	7.9
Kuwait	35.5	6.6
Kyrgyzstan	198.0	1.2
Latvia	99.3	2.4
Lebanon	29.8	7.9
Libya	39.6	5.9
Lithuania	93.8	2.5
Luxembourg	171.1	1.4
Macedonia	46.1	5.1
Malaysia	43.2	5.4
Malta	31.0	7.6
Mauritius	30.9	7.6
Mexico	56.2	4.2
Moldova	61.0	3.9
Mongolia	29.9	7.9
Montenegro	57.3	4.1
Morocco	39.0	6.0
Mozambique	378.2	0.6
Myanmar	132.0	1.8
Namibia	1047.1	0.2
Nepal	5071.3	0.05
Netherlands	44.4	5.3
New Zealand	203.0	1.2
Nicaragua	50.6	4.6
Niger	29.2	8.1
Nigeria	70.7	3.3
Norway	1820.6	0.1

(continued)

Appendix (continued)

Country	MPG-equivalent	L/100 km
Oman	56.5	4.2
Pakistan	57.5	4.1
Panama	82.4	2.9
Paraguay	5084.1	0.05
Peru	113.4	2.1
Philippines	44.8	5.3
Poland	32.4	7.3
Portugal	65.8	3.6
Qatar	58.0	4.1
Romania	79.9	2.9
Russian Federation	70.7	3.3
Saudi Arabia	40.2	5.9
Senegal	32.6	7.2
Serbia	40.5	5.8
Singapore	57.0	4.1
Slovak Republic	152.5	1.5
Slovenia	91.1	2.6
South Africa	31.5	7.5
South Sudan	29.2	8.1
Spain	80.5	2.9
Sri Lanka	55.7	4.2
Sudan	80.9	2.9
Suriname	72.0	3.3
Sweden	1421.6	0.2
Switzerland	1905.3	0.1
Syria	45.7	5.1
Taipei	43.3	5.4
Tajikistan	1389.8	0.2
Tanzania	65.5	3.6
Thailand	49.6	4.7
Togo	108.5	2.2
Trinidad and Tobago	57.9	4.1
Tunisia	56.9	4.1
Turkey	58.5	4.0
Turkmenistan	58.0	4.1
Ukraine	75.0	3.1
United Arab Emirates	57.4	4.1
United Kingdom	67.8	3.5
United States	55.4	4.2
Uruguay	210.4	1.1
Uzbekistan	69.1	3.4
Venezuela	107.6	2.2
Viet Nam	61.8	3.8
Yemen	36.2	6.5
Zambia	815.1	0.3
Zimbabwe	60.2	3.9