Electronic Supplementary Information

Indirect emissions from electric vehicles: Emissions from electricity generation

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The following provides further details on the data and calculations used in the paper, organised by section. All data are for 2006, the last year for which all data were available. Figures in italics are the result of calculations based on data from the given sources. Reference numbers and table numbers refer to those in the paper.

Introduction

- **Average capacity factor (C) of electricity generation in the US, the UK, and France**

$$C = \frac{Net\ electricity\ generation\ (GWh)}{Total\ installed\ capacity\ (GW) \times (8760\ h)}$$

Calculated from the following data:

	Net electricity generation (GWh)	Total installed capacity (GW)
US	4 065 000 [10]	964.754 [11]
UK	*339 283* [12]	74.996 [12]
France	*541 327* [14]	112.022 [11]

EVs

- **Amount of electricity generation required (E) to run the three EVs considered in this study in each country, including transmission and distribution (T+D) losses**

$$E = Electricity\ required\ from\ mains\ (kWh/km) \times \frac{1}{1 - \left(T + D\ losses\ (\%)\right)}$$

Calculated from the following data:

	Tesla Roadster	TH!NK City	REVAi
Driving range (km)	354 [a]	175 [b]	80 [c]
Battery charging requirements (kWh/km)	0.19 [d]	-	-
Energy required to fully charge battery (kWh)	*68.2*	30 [e]	*11.0*
Battery capacity (kWh)	~53 [f]	28.3 [b] (sodium option)	9.6 [g]
Loss due to charging inefficiency (%)	*22*	*6*	13 [h]
Electricity required from mains (kWh/km) [i]	*0.192*	*0.171*	*0.138*

[a] www.teslamotors.com/performance/perf_specs.php
[b] www.think.no/think/TH!NK-city/Specifications/Technical-data
[c] www.revaindia.com/ebrochures.htm
[d] www.teslamotors.com/blog4/?p=60; converted from 31 kWh / 100 mi
[e] www.think.no/think/Our-Company/FAQ
[f] www.teslamotors.com/display_data/TeslaRoadsterBatterySystem.pdf
[g] Calculated from battery charge (200 A·h) and voltage (48 V)
[h] Personal communication from M. Boxwell (see paper)
[i] Not including transmission and distribution losses

Transmission and distribution (T+D) losses:

	T+D losses (GWh)	Electricity consumption (GWh)	T+D losses (%) [a]
US [10]	266 000	*3 670 000*	*7.2*
UK [12]	*26 289*	*330 440*	*8.0*
France [14]	31 811	*446 181*	*7.1*

[a] Calculated as a share of consumption by end users from the total net supply of electricity from the public distribution system in each country

- **Average CO_2 emissions from electricity generation in each country**

Calculated from net electricity generation (above) and the amount of CO_2 emitted by electrical power plants (kt):

US 2 459 800 (36)
UK 50 300 as carbon (12)
France 47 433.53 (38)

- **Share of electricity in the US, the UK, and France generated from fossil fuels**

Calculated from total net electricity generation (above) and electricity generation from fossil fuels (GWh):

US 2 884 400 (10)
UK *261 132* (12)
France *56 281* (14)

- **Average well-to-wheels (WtW) CO_2 emissions for each EV in each country**

Calculated as the sum of well-to-power-plant (WtPP) CO_2 emissions and power-plant-to-wheels (PPtW) CO_2 emissions, as described in the paper. The table below shows the calculation of the figures in Table 6.

US	Coal	Oil	Gas	Nuclear	Total emissions		
					WtPP	PPtW	WtW
Emissions from electricity generation (g CO_2/kWh)							
Share of generation (%) (Table 4)	49.0	1.6	20.0	19.4			
WtPP emissions (Table 5)	110	75	74	40			
Share of WtPP emissions	*53.9*	*1.2*	*14.8*	*7.8*	*77.7* [a]		
Average emissions from electricity generation (Table 3)						*605.1*	
EV emissions (g CO_2/km, at right) and efficiency (kWh/km, below)							
Tesla Roadster (0.207) (Table 2)					*16.1* [b]	*125.3* [c]	*141*
TH!NK City (0.184)					*14.3*	*111.3*	*126*
REVAi (0.149)					*11.6*	*90.2*	*102*

UK	Coal	Oil	Gas	Nuclear	Total emissions		
					WtPP	PPtW	WtW
Emissions from electricity generation (g CO_2/kWh)							
Share of generation (%)	40.1	0.8	36.0	20.1			
WtPP emissions	110	75	74	40			
Share of WtPP emissions	*44.1*	*0.6*	*26.6*	*8.0*	*79.4*		
Average emissions from electricity generation						543.5	
EV emissions (g CO_2/km, at right) and efficiency (kWh/km, below)							
Tesla Roadster (0.209)					*16.6*	*113.6*	*130*
TH!NK City (0.186)					*14.8*	*101.1*	*116*
REVAi (0.150)					*11.9*	*81.5*	*93*

France	Coal	Oil	Gas	Nuclear	Total emissions		
					WtPP	PPtW	WtW
Emissions from electricity							

generation (g CO_2/kWh)							
Share of generation (%)	3.9	0.9	3.6	78.1			
WtPP emissions	110	75	74	40			
Share of WtPP emissions	*4.3*	*0.7*	*2.7*	*31.2*	*38.9*		
Average emissions from electricity generation						87.6	
EV emissions (g CO_2/km, at right) and efficiency (kWh/km, below)							
Tesla Roadster (0.207)					*8.0*	*18.1*	*26*
TH!NK City (0.184)					*7.2*	*16.1*	*23*
REVAi (0.149)					*5.8*	*13.1*	*19*

[a] Total WtPP emissions, summed over the four fuel types. Figures may not add to totals due to rounding.
[b] Total WtPP emissions multiplied by EV fuel efficiency
[c] National average CO_2 emissions from electricity generation multiplied by EV fuel efficiency

For comparison to the ICEV and HEV fuel efficiency data below, the efficiencies cited above are as follows in MJ/km:

	Tesla Roadster	TH!NK City	REVAi
US	0.75	0.66	0.54
UK	0.75	0.67	0.54
France	0.75	0.66	0.54

- **Average efficiency of electricity generation and supply to end users in each country**

Defined as the electricity consumed by end users (calculated from net electricity generation and transmission and distribution losses for each country) as a share of the energy consumed to generate the electricity (GWh):

US	12 085 000 [(10)]
UK	912 214 [(12)]
France	1 370 000 [(23)]

The electricity consumed by end users was calculated as net electricity generation for each country less transmission and distribution losses and direct use – that is, electricity that is produced and consumed by the same entity.

ICEVs and HEVs

- **Well-to-wheels CO_2 emissions for a selection of ICEVs and HEVs**

Calculated from well-to-tank (WtT) CO_2 emissions and tank-to-wheels (TtW) CO_2 emissions, as described in the paper. Data used in the calculations are shown in the table below.

Model [a]	Class	Fuel efficiency [b] (MJ/km)	Emissions (g CO_2/km)		
			WtT [c]	TtW [b]	WtW
Smart fortwo (diesel)	Supermini	1.19	*24.8*	88	***113***
Toyota Prius T3	Small family	1.27	*26.4*	89	***115***
SEAT Ibiza	Supermini	1.37	*28.5*	99	***127***
Volkswagen Polo	Supermini	1.37	*28.5*	99	***127***
Toyota iQ	Supermini	1.40	*29.1*	99	***128***
Smart fortwo (petrol)	Supermini	1.40	*29.1*	103	***132***
Honda Civic Hybrid	Small family	1.50	*31.2*	109	***140***
Mini Cooper Clubman	Estate	1.79	*37.2*	132	***169***
Lotus Elise	Open-top	2.87	*59.7*	208	***268***
Porsche Boxster	Open-top	3.06	*63.6*	221	***285***

[a] The 2009 model year is used for all.
[b] www.vcacarfueldata.org.uk (UK Government's Vehicle Certification Agency)

[c] Fuel efficiency multiplied by the well-to-tank CO_2 emissions figure for oil (includes refining) in g/MJ (75 g/kWh = 20.8 g/MJ).

Fleets

- **Average well-to-wheels CO_2 emissions of a hypothetical EV fleet in each country**

Calculated as described in the paper

- **Well-to-wheels CO_2 emissions for existing passenger car fleets in each country**

Calculated from well-to-tank CO_2 emissions and tank-to-wheels CO_2 emissions

Fleet well-to-tank CO_2 emissions were calculated from the well-to-tank CO_2 emissions figure for oil from Table, as for the individual ICEVs and HEVs, and from fleet fuel efficiency. Fleet fuel efficiency was calculated from the net calorific value of fuel consumed by the fleet and from the number of vehicle kilometres driven by the fleet:

Fleet fuel consumption:

	Gasoline	Diesel
US (gal) [27-29]	*7.1734 x 10^{10}*	*4.07 x 10^{8}*
UK (metric t) [25]	1.729 x 10^{7}	4 58 x 10^{6}
France (L) [13]	1.1533 x 10^{10}	1.5585 x 10^{10}

With calorific conversion factors from (10) and (12), including average net calorific values for petrol and diesel of 32.6 and 36.0 MJ/L, respectively

Vehicle kilometres driven by passenger car fleet:
US: 2.720651 x 10^{12} [28]
UK: 4.026 x 10^{11} [25]
France: 3.958 x 10^{11} [13]

Fleet tank-to-wheels CO_2 emissions were calculated from the number of vehicle kilometres travelled by the fleet and from fleet CO_2 emissions (kt):

US: 634 500 [29]
UK: 18 900 as carbon [37]
France: 129 781.76 for all road transportation [38], of which 54.7% is from passenger cars [42]

Fleet well-to-wheels CO_2 emissions for the 2006 model year in the US were calculated in the above manner with the following data (cited in the paper):

Average fuel efficiency for the 2006 model year: 30.1 mpg [28]

CO_2 emissions from the US passenger car fleet: 630 400 kt from gasoline cars and 4 100 kt from diesel cars [29] (the figures for fleet emissions are scaled using fleet fuel economy to approximate the emissions intensity for the 2006 model year alone)

Carbon content per gallon of fuel: 2.421 kg for gasoline and 2.778 kg for diesel [27]

The proportion of light-duty trucks in each fleet was calculated from the following data:

	Registered passenger cars	Registered light-duty trucks
US [28]	135 399 945	99 124 775
UK [25]	27 873 000	3 053 000
France [42]	30 250 000	5 590 000

- **Increase in electricity consumption that could occur in each country if all passenger cars were EVs with the average electricity demand of the three EVs studied here**

Calculated from the amount of electricity generation required to run the three EVs (see above), the number of vehicle kilometres travelled per year by the national passenger car fleet in each country, and the net consumption of electricity in each country

- **Change in electricity demand profile that could occur by meeting half of the demand of the hypothetical electric vehicle fleet in the example of the UK**

Calculated using half-hourly demand figures for each day of the year from the national grid operator (www.nationalgrid.com/uk/Electricity/Data)

Overall comparison

- **Average CO_2 emissions from in-state electricity generation in individual US states**

Calculated as above for the three countries, using the following data, which show states with the highest and lowest average emissions intensity in in-state[§] electricity generation:

State	Net generation (GWh) [a]	CO_2 emissions (kt) [b]
North Dakota	30 881	31 266.8
Wyoming	45 400	45 215.6
Kentucky	98 792	93 160.1
Indiana	130 490	121 950.2
West Virginia	93 816	85 075.5
. . .		
California	216 799	59 389.0
Oregon	53 341	7 087.8
Washington	108 203	10 359.5
Idaho	13 386	875.3
Vermont	7 084	10.2

[a] www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls
[b] www.eia.doe.gov/cneaf/electricity/epa/emission_state.xls

The paper states that in twelve states more than 70 percent of in-state electricity generation comes from coal. The states are as follows:

State	Share of in-state electricity generation coming from coal (%) [a]
West Virginia	*97.5*
Indiana	*94.8*
Wyoming	*94.5*
North Dakota	*93.5*
Kentucky	*92.3*
Utah	*89.3*
Ohio	*85.8*
Missouri	*84.5*
New Mexico	*80.1*
Iowa	*75.6*
Kansas	*73.1*
Colorado	*71.5*

[a] www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls

The paper also states that in four states more than 70 percent of in-state electricity generation comes from nuclear and renewable sources. The states are as follows:

[§] As described in the paper, these values are indicative only, as electricity in much of the US is generated and transmitted on a regional basis, in regions that may span several states and may not follow state boundaries.

State	Share of in-state electricity generation coming from . . . [a]			Total (%) [b]
	Nuclear (%)	Hydro (%)	Other renewables (%)	
Vermont	*72.1*	*21.4*	*0.2*	*93.7*
Washington	*8.6*	*75.8*	*1.0*	*85.3*
Idaho	*0.0*	*84.0*	*1.3*	*85.3*
Oregon	*0.0*	*71.0*	*1.7*	*72.7*

[a] www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls
[b] Percentages may not add to totals due to rounding.

The eight French regions in which more than 95 percent of in-region electricity generation comes from nuclear and renewable sources are as follows:

Region	Share of in-region electricity generation coming from . . . [14]		Total (%) [b]
	Nuclear (%)	Renewables (%) [a]	
Alsace	*58.3*	*38.2*	*96.5*
Aquitane	*90.2*	*4.9*	*95.1*
Basse-Normandie	*99.0*	*0.5*	*99.6*
Centre	*97.7*	*0.5*	*98.2*
Champagne-Ardenne	*95.5*	*3.2*	*98.7*
Midi-Pyrénées	*65.8*	*31.3*	*97.1*
Poitou-Charentes	*98.0*	*0.6*	*98.6*
Rhône-Alpes	*76.1*	*21.8*	*97.9*

[a] A breakdown of this figure is not provided.
[b] Percentages may not add to totals due to rounding.

- **Average well-to-wheels CO_2 emissions for EVs if using electricity generated from a single fuel**

Calculated as for the EVs in Table 6