Method of Stating Energy Consumption

Life-cycle analysis for EV energy consumption results

Part 1: Literature review

A. Many papers are related to the assessment of energy saving and GHG emission reductions of EV in different countries or districts.
B. Upstream stage of power supply should be covered for EV assessment.
C. The data of electricity mix and upstream emissions factor of different power supplying can be collected in most of countries.
D. A standardized method for calculating and stating energy consumption and the associated GHG emissions for electrified vehicles is therefore recommended for consideration.

A. Many recent papers on EV energy consumption and CO2 emissions in different countries/districts

- For EU and its members
  - Rangaraju et al. (2015); Buekers et al. (2014); Donateo et al. (2015); Ma et al. (2012); Millo et al. (2014); Sánchez et al. (2013); Brouwer et al. (2013); Jochem et al. (2015); Faria et al. (2013); Holdway et al. (2010); Smith (2010)
- For US
  - Huo et al. (2015); Holdway et al. (2010); Millo et al. (2014); Thomas (2012a,b); Kim et al. (2014) ; Yang (2013)
- For China
  - Huo et al. (2015); Millo et al. (2014); Zhou et al. (2013); Ou et al. (2010)
- For Others (i.e. Japan)
  - Millo et al. (2014); Zhang et al. (2013)

B. Upstream stage of power supply should be covered for EV assessment.

- The emissions from EVs depend on their own energy consumption and on the CO2 intensity of the power generation mix from which the EV’s energy should obtained. (Doucette and McCulloch (2011))
- The energy consumption is the amount of energy used per unit distance traveled.
- The CO2 intensity of a power generation mix is the average amount of CO2 emitted per unit of electrical energy generated by all of the power production processes in a mix weighted by the amount of power obtained from each of those processes.

- Ou et al. (2010) for China

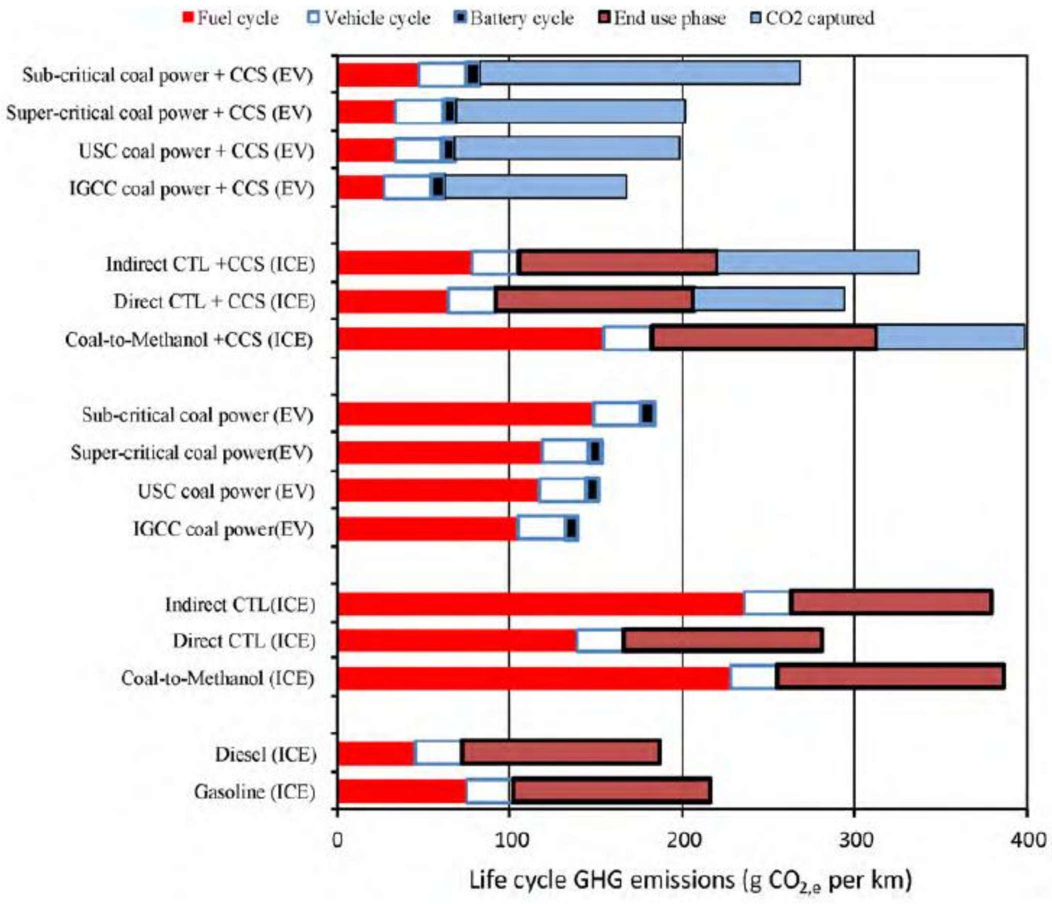


Fig. 3. Life cycle GHG emissions for CTL vehicle and EV in the high process efficiency configuration.

- Ma et al. (2012) for UK

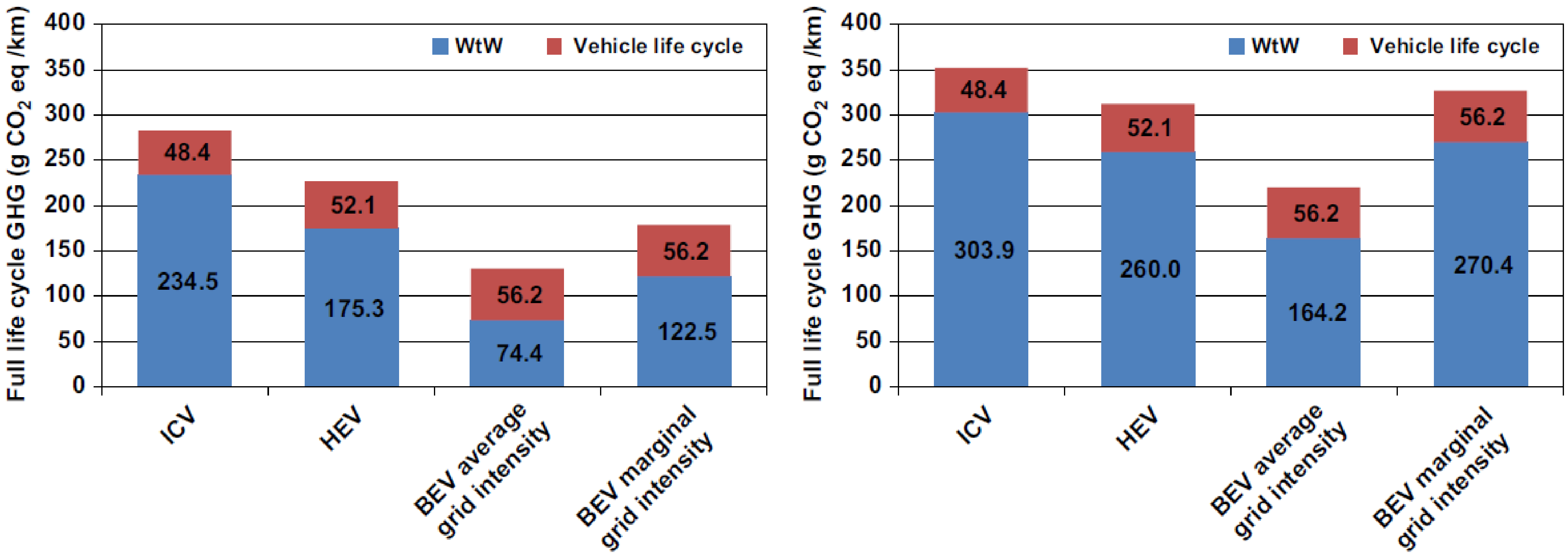


Fig. 4. Comparison of the WtW and Vehicle life cycle emissions from matched SUV-class ICV, HEV and BEV in California in 2015 (15-year vehicle life time, 19,300 km/year): left – lower speed and load (urban, driver only, no accessory) driving conditions; right – higher speed and load (extra-urban, driver + loading, accessory) driving conditions. **NOTE** – the methodologies adopted in this work can be readily applied to plug-in hybrid electric vehicles (PHEVs), and their results will most likely fall between those of HEVs and BEVs, on a like-for-like basis, primarily because:

- Holdway et al. (2010) for UK, US and France

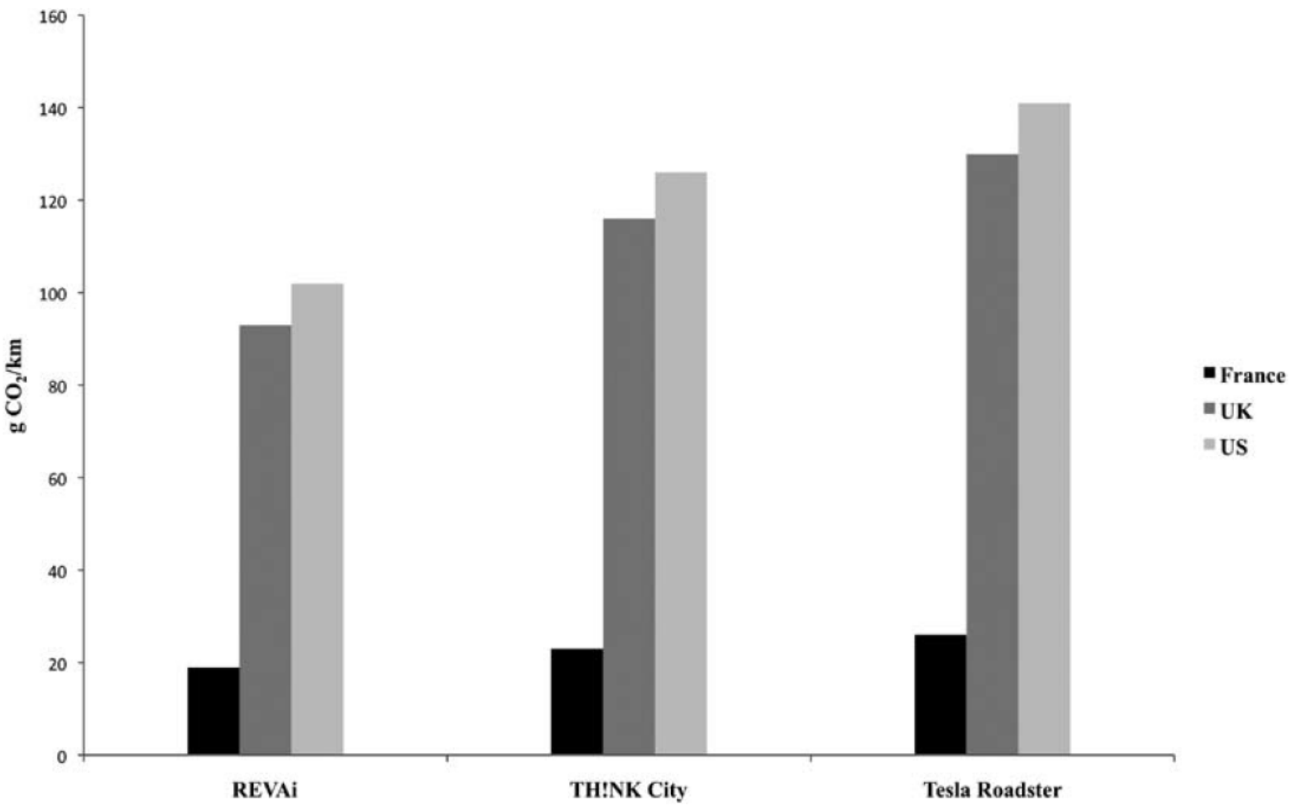
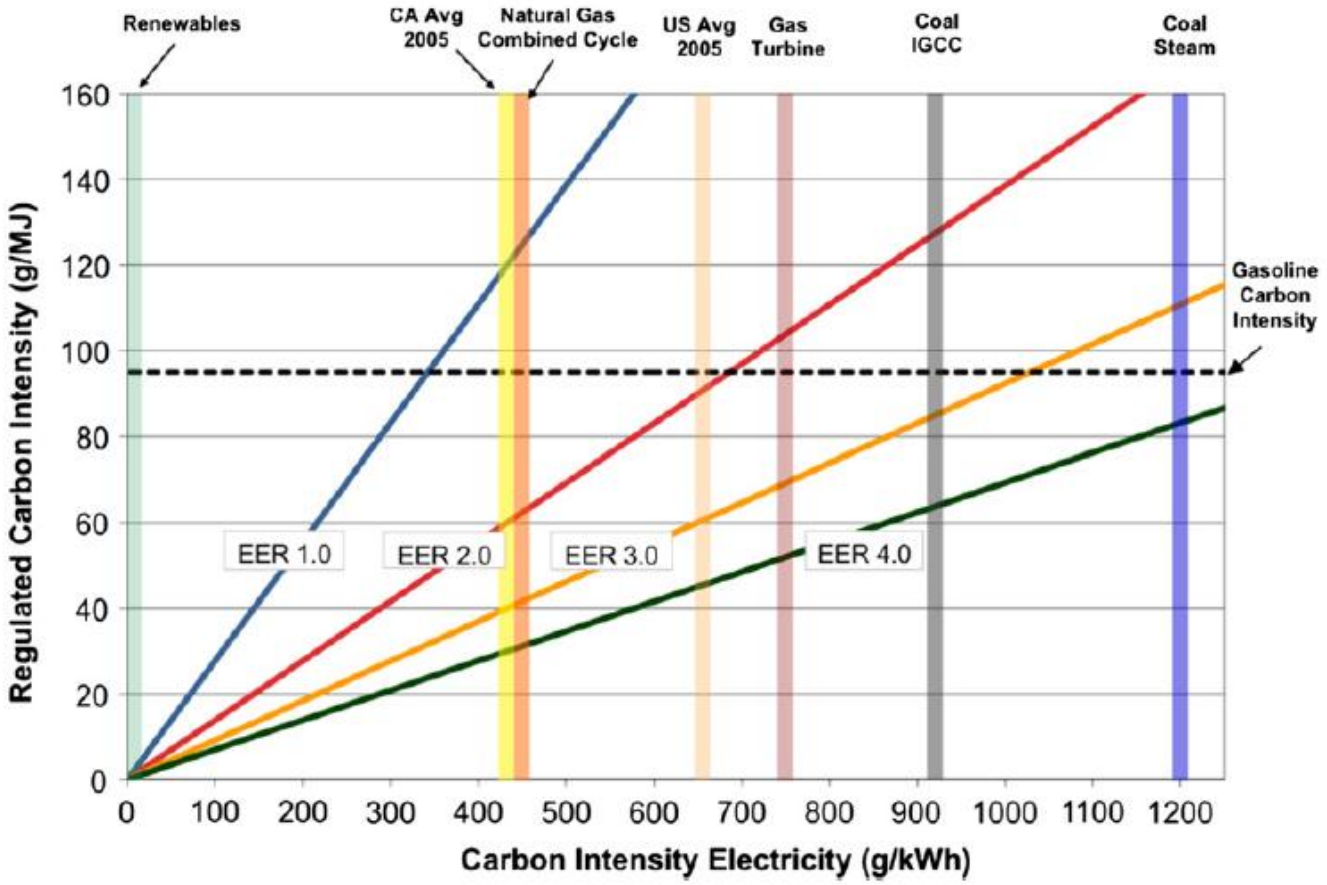


Fig. 1 Average well-to-wheels CO_2 emissions for EVs (g CO_2 per km) plotted from the data in Table 6.

- Yang (2013) for US



C. The data of electricity mix and upstream emissions factor can be collected usually.

- The emissions from EVs depend on their own energy consumption and on the CO2 intensity of the power generation mix from which the EV's energy should obtained. (Doucette and McCulloch (2011))
- The CO2 intensity varies considerably depending on the composition of the power generation mix.

- Buekers et al. (2014) for EU

Table 2
General air pollutant emissions (kg/kWh) from electricity production (chain analysis of construction, operation, fuel provision and dismantling) for all EU countries. Country and time specific energy mix determines absolute emissions. Data are based on the life cycle inventory data from the FP6 project CASES.[1]

	Emissions (kg/kWh)						
	NH_3	NO_x	SO_2	$PM_{2.5-10}$	$PM_{2.5}$	NMVOC	CO_2
Nuclear power plant	6.30×10^{-6}	4.27×10^{-5}	6.86×10^{-5}	2.34×10^{-6}	6.19×10^{-6}	6.55×10^{-6}	1.21×10^{-2}
Light oil gas turbine	3.15×10^{-6}	6.51×10^{-4}	9.90×10^{-4}	1.28×10^{-5}	3.71×10^{-5}	2.79×10^{-4}	8.53×10^{-1}
Hard coal IGCC	1.83×10^{-5}	5.98×10^{-4}	3.34×10^{-4}	1.76×10^{-5}	1.53×10^{-5}	6.09×10^{-5}	6.19×10^{-1}
Lignite IGCC	4.71×10^{-7}	3.92×10^{-4}	5.90×10^{-4}	2.04×10^{-6}	2.91×10^{-6}	8.50×10^{-6}	7.76×10^{-1}
Natural gas	2.12×10^{-7}	1.95×10^{-4}	1.38×10^{-4}	3.56×10^{-6}	7.09×10^{-6}	9.81×10^{-5}	3.73×10^{-1}
Waterpower	3.10×10^{-7}	7.57×10^{-5}	2.30×10^{-5}	5.28×10^{-5}	1.75×10^{-5}	2.95×10^{-5}	1.22×10^{-2}
Wind	3.89×10^{-7}	2.60×10^{-5}	2.76×10^{-5}	6.29×10^{-6}	4.02×10^{-6}	4.68×10^{-6}	9.08×10^{-3}
Biomass	4.93×10^{-5}	1.76×10^{-3}	1.43×10^{-4}	4.86×10^{-5}	4.25×10^{-5}	2.22×10^{-4}	1.80×10^{-2}
Photovoltaic cells	2.45×10^{-6}	1.12×10^{-4}	1.68×10^{-4}	2.90×10^{-5}	2.41×10^{-5}	1.96×10^{-5}	5.35×10^{-2}

IGCC: Integrated Gasification Combined Cycle.
[1] : http://www.feem-project.net/cases/documents/1LCI_Data_080515.xls.

- Ma et al. (2012) for UK

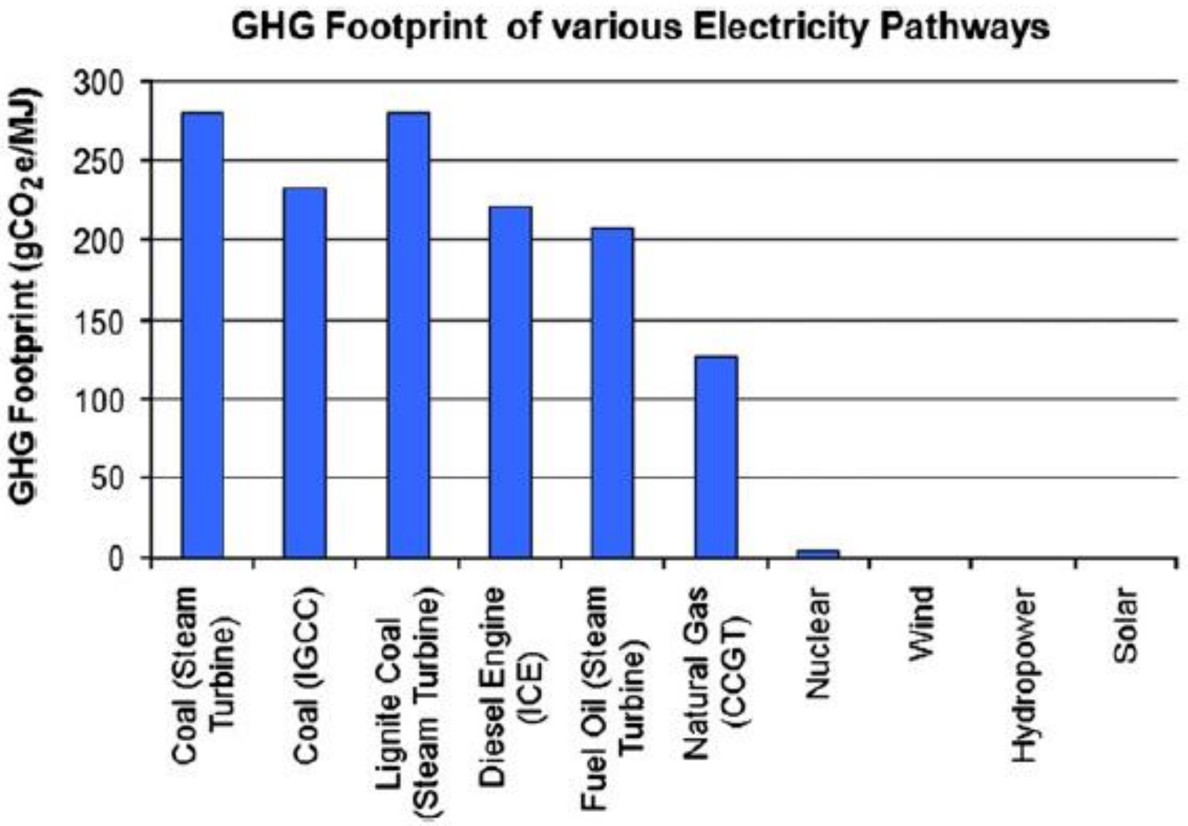


Fig. A1. GHG emissions intensity of different feedstocks/technologies for electricity generation.

- Zhang et al. (2013) for Japan

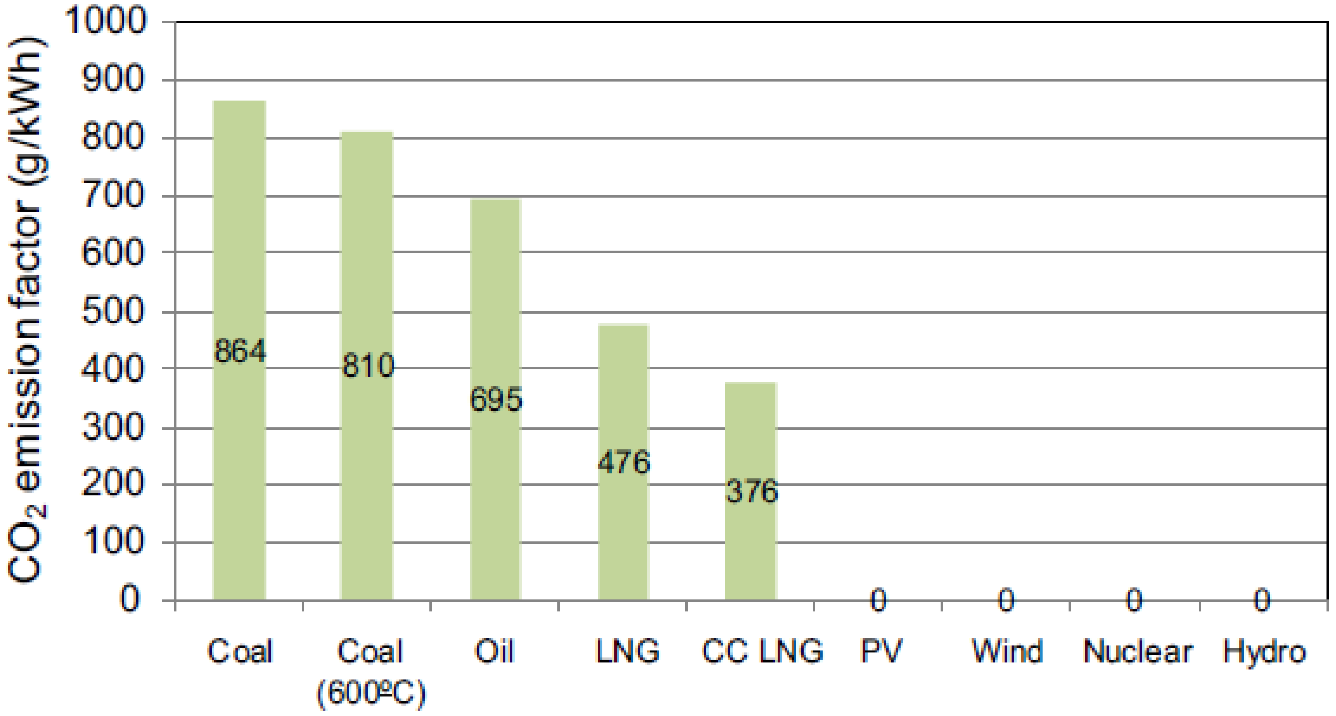


Fig. 8. CO_2 emissions factors of various electricity generation technologies.

- Holdway et al. (2010) for UK

Table 5 Well-to-power-plant CO_2 emissions by type of fuel used in electricity generation (g CO_2 per kW h)[a]

	Coal[39] [b]	Oil[40] [c]	Natural gas[39] [d]	Nuclear[7] [e]
Range	85–135	40–110	48–100	9–70
Mean[f]	110	75	74	40

[a] The well-to-power-plant CO_2 emissions for hydro power (1.9 g CO_2 per

- Ou et al. (2011) for China

Table 8
WTM results for electricity supply by feedstock type.

Item	Unit	Feedstock type						
		Coal	Oil	NG	Nuclear	Biomass	Others	Mixed
Fossil energy use	MJ/MJ	3.869	5.373	3.238	0.063	0.076	0.000	3.247
Coal use	MJ/MJ	3.503	1.150	0.482	0.052	0.010	0.000	2.855
NG use	MJ/MJ	0.007	0.188	2.561	0.005	0.002	0.000	0.027
Oil use	MJ/MJ	0.359	4.036	0.195	0.006	0.064	0.000	0.365
GHG emissions	g $CO_{2,e}$/MJ	357.707	340.956	236.956	6.506	5.846	5.000	297.688
CO_2	g/MJ	297.464	328.225	228.343	5.920	2.221	0.000	247.972
CH_4	g/MJ	2.610	0.525	0.367	0.025	0.006	0.217	2.154
N_2O	mg/MJ	0.692	2.217	0.563	0.000	11.771	0.000	0.615

- Millo et al. (2014) for many countries

Table 4
CIE (gCO_2/kW h) of different countries in recent years [28].

	2003	2004	2005	2006	2007	2008	2009	Average 07
World	495	500	500	503	508	504	500	504
US	571	571	570	542	549	535	508	531
Japan	444	427	429	418	452	438	415	435
France	81	79	93	87	90	87	90	89
Germany	434	436	406	404	468	441	430	447
Italy	511	459	449	468	440	421	386	416
The United Kingdom	478	486	485	507	499	490	450	480
OECD Europe	358	351	343	348	357	340	326	341
China	776	804	787	787	758	744	743	748
India	892	931	923	921	943	954	951	950

- Huo et al. (2015) for China and US

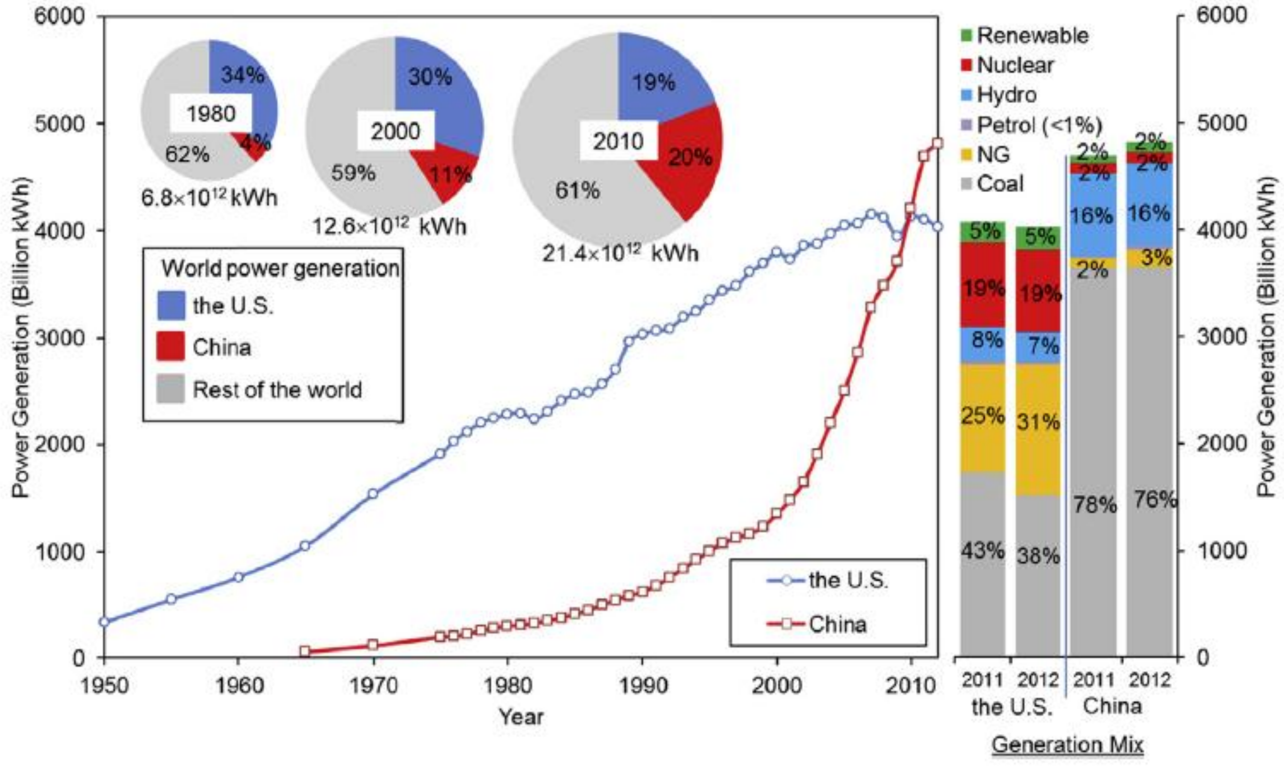


Fig. 2. Historical total electricity generation and generation mixes in the U.S. and China.

- Thomas (2012) for US

Table 9 – Percentage of US electricity projected by the EIA's 2011 Annual Energy Outlook reference case.

	2010	2015	2020	2035
Residual Oil	1.0%	0.9%	1.0%	0.9%
Natural Gas	23.1%	20.9%	19.9%	21.9%
Coal	46.2%	44.6%	45.2%	45.8%
Total Fossil Fuels:	70.3%	66.4%	66.1%	68.6%
Nuclear	20.3%	21.0%	21.3%	19.0%
Renewables other	9.4%	12.5%	12.7%	12.3%

- Jochem et al. (2015) for Gemany

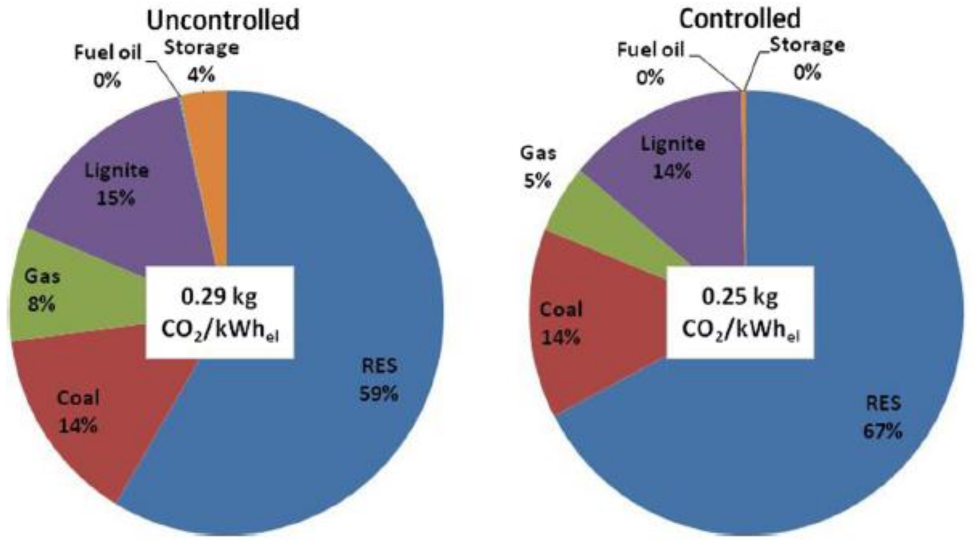


Fig. 7. Time-dependent average electricity mix for EV charging in Germany in 2030.

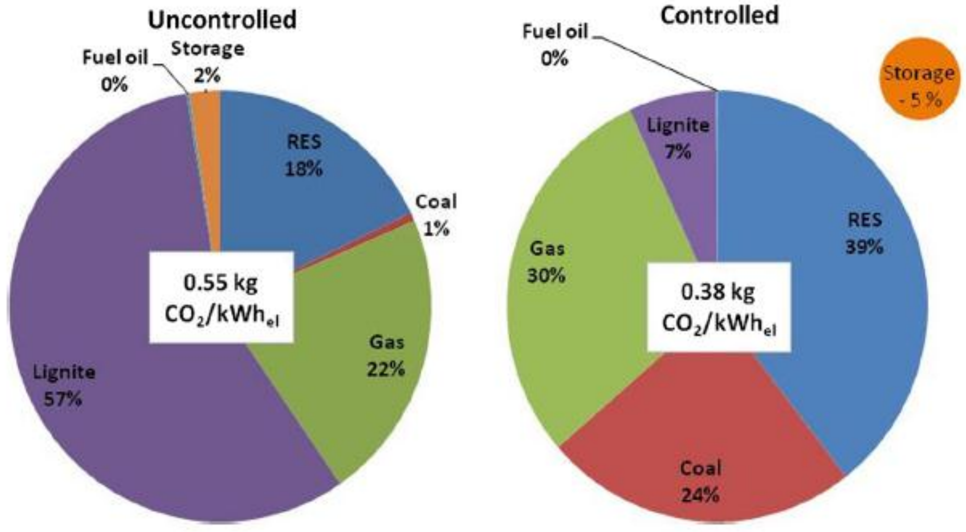


Fig. 8. Marginal mix for uncontrolled and controlled charging of EV in Germany in 2030.

- Faria et al. (2013) for EU

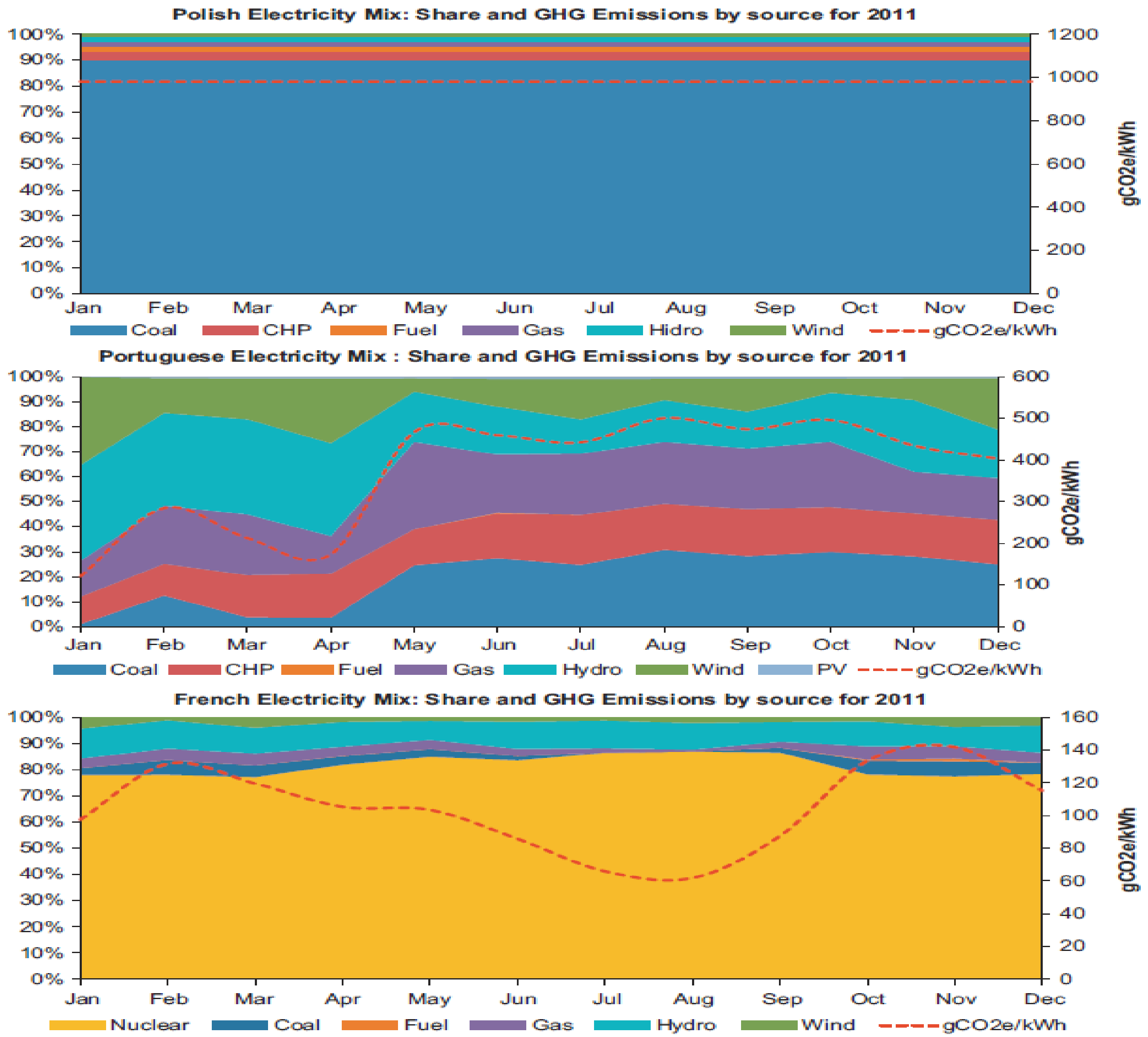


Fig. 5. Electricity mixes share and associated GHG emissions.

• Rangaraju et al. (2015) for Belgium

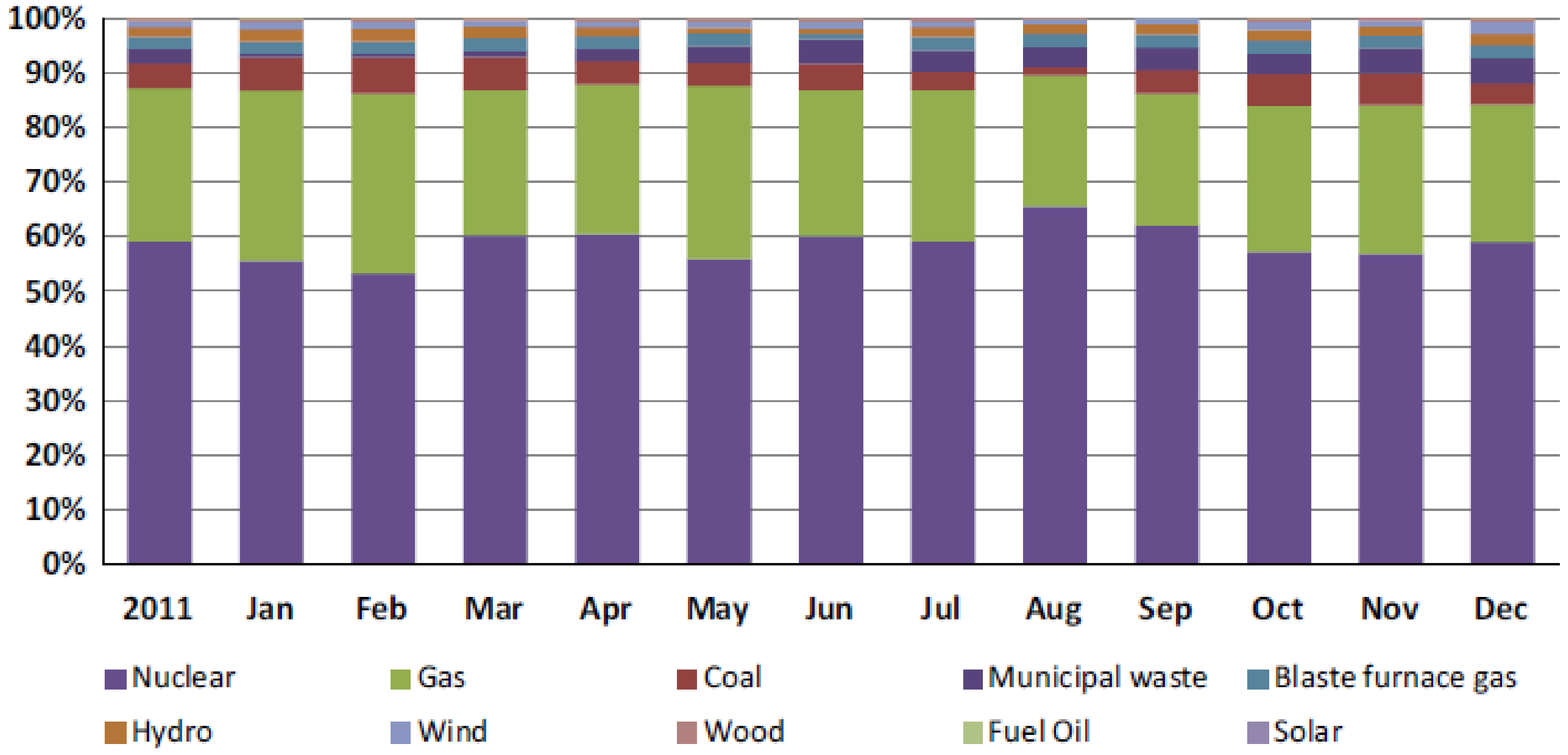


Fig. 3. Contribution of different fuels to the electricity mix in each month in 2011.

- Smith (2010) for Ireland

Fuel source	Fuel input (ktoe)	Electricity Generated (GWh)	CO_2 emission factor (kt $ktoe^{-1}$)	CO_2 emissions (kt)
Coal	373	1596	3.961	1477
Oil	345	1367	3.069	1059
Gas	2397	15,773	2.382	5710
Peat	338	1398	4.886	1651
Biomass	500	2132		
Hydro	91	1053		
Ocean	118	1367		
Wind	718	8347		
Gross	4879	33,033		9898

D. Stating Energy Consumption is an important environmental issue.

- The development of such an assessment method is important as the expected increase in use of electric vehicles will lead to displaced emissions from the vehicle to electricity grids; depending on the GHG accounting methods used, the impact of electric vehicles on a region's emissions profile may be underestimated if only considered for transportation.
- However, the development of such a method is very challenging. It requires expertise in the composition of regional electrical grids as well as knowledge of the energy consumed for both electricity generation and distribution and conventional fuel production and distribution.
- In addition, vehicle energy sources and their associated GHG emissions are geographically highly variable.

It is recommended that a method be developed rather than attempt to establish a common value.

- The method could consider the following:
  - Vehicle energy source upstream emissions;
  - Applicability to fleet average calculations;
  - Specific energy sources used by the vehicle and operating conditions can vary by region and are not managed by the vehicle manufacturer;
  - Easily understood by the consumer;
  - Of interest to the consumer in the context of comparing products;
  - Flexible enough to cover a wide range of propulsion system technologies;
  - Adopted widely across vehicle manufacturers;
  - Adopted widely across the world.

Other considerations for electrified vehicle energy consumption

- Include:
  - geographical and seasonal variation in liquid fuel lower heating values, and the relative efficiency associated with the upstream production of fuels and other energy carriers.
  - The latter can vary depending on the method of power generation and source of raw input energy (heavy fuel, gas, biofuel, wind, solar, hydro etc.).

Part 2: DATA collection

- Data on electricity chains
  - Life cycle energy consumption and GHG emissions situation for fossil fuel production and distribution stages of power generation
    - MJ/MJ fuel obtained
    - g CO2,e /MJ fuel obtained
  - Electricity generation efficiency (%, by type)
  - Life cycle energy consumption and GHG emissions situation for non fossil fuel power generation and supplying
    - MJ/MJ power supplying
    - g CO2,e /MJ power supplying
  - Composition of regional electrical grids (%)(Coal, Oil, Gas, Hydro, Nuclear, PV, Wind and others)
  - Electricity transmission loss (%)
- Data on EV charging and running
  - Charging efficiency (%)
  - Energy consumption for EV running (kWh /100 km)

Part 3: Calculation methods

- Life cycle analysis results
  Please see the formula in Cell D52 and Cell D56
  - Energy consumption
    - D52=3.6*D47/D43/(1-D38/100)*(D27/100/(D12/100)*D7+D28/100/(D13/100)*D8+D29/100/(D14/100)*D9+D30/100*D19+D31/100*D20+D32/100*D21+D33/100*D22*+D34/100*D23)
  - GHG emissions
    - D56=3.6*D47/D43/(1-D38/100)*(D27/100/(D12/100)*F7+D28/100/(D13/100)*F8+D29/100/(D14/100)*F9+D30/100*F19+D31/100*F20+D32/100*F21+D33/100*F22*+D34/100*F23)

Part 4: Stating Methods

- Labelling together
  - ** kWh /100 km
  - ** Liter (gasoline equivalent)/ 100 km
- Considering energy consumption by upstream and operation stages
  - Upstream (percentile)
  - Operation (percentile)
- Comparing GHG emissions to conventional gasoline vehicle
  - Total
  - By stages