Electrification
Data Methodology 2024

Overview

Output metrics

Ember's annual electrification data quantifies the impact of electrification on the national energy balance by calculating the following metrics based on real-world data on sectoral activities and technology roll-out in transport and residential heating sectors:

- Electricity demand from electrification technologies in GWh. Notably, electric vehicles for transport sector, and residential heat pumps in domestic sector)
    - Share of electricity demand from electrification out of total electricity demand (%)
- Primary Fossil fuel consumption displaced through electrification in GWh and barrels of oil
- Emissions displaced through electrification in CO2 equivalent

Input data

Input data on real-world data on sectoral activities include:

Road transport

- Stock of battery electric and plug-in hybrid vehicles by vehicle type. Vehicle types include Buses, Cars, Trucks and Vans.
- Total stock of all vehicles by vehicle type.
- Number of newly registered battery electric and plug-in hybrid vehicles by vehicle type.
- Annual traffic data by vehicle type, measured in vehicle-km.
- Average vehicle fuel efficiency by vehicle type. This is the amount of electricity required to drive a unit of distance, measured in watt hours/km.
- Annual average age of current vehicle fleet.

Residential heating

- Stock of heat pumps.
- Number of households.
- Final energy consumption for domestic heating (water and space) by fuel in terajoules.
    - For the United Kingdom, missing data by calculating the historical average of share of heat in final energy consumption (76%) to the latest year's final energy consumption for the residential sector.
- Efficiency factor for residential heating
    - From the fuel breakdown of final energy consumption for domestic heating, we derive an energy efficiency factor. It is used to convert final energy consumption for residential heating to useful energy demand. This is the "boiler efficiency" across all fuels for residential heating. More precisely, it is the weighted average of assumed fuel efficiencies (fossil: 81.5%, electricity/alternative: 100%). Fuel efficiency assumptions are from the US energy agency.
    - For the United Kingdom, latest year data is estimated by taking the cagr of historical change due to missing data.

- Seasonal coefficient of performance by country and year.

Other input data and assumptions include:

Electricity Generation

- Total annual electricity demand by country and year.
- Primary fossil fuel input required to generate one unit of electricity. This metric is the sum of primary fuel input by fuel type, which is calculated by dividing the annual power mix of a country by power plant efficiencies reported by Ladage et al. (2021) and Guidehouse (2018). One limitation of this metric is that constant power plant efficiencies are applied across all countries and years. However, the effect of power plant efficiency improvements is much smaller than the efficiency improvements from change in power mix.
    - Lignite: 39%
    - Hard coal: 44%
    - Fossil gas: 55%
    - Other Fossil: 40%

Lifecycle emissions factors

- Emissions intensity of electricity in gCO2 per kWh, by country and year (Ember calculation).
- Emissions intensity of oil combustion for mobility from Edwards et al (2004)., as cited in Buberger et al (2022). Note that emissions from methane leakage are underestimated.
- Emissions intensity of stationary gas combustion from Greenhouse Gas Protocol. Note that emissions from methane leakage are underestimated.

Transport

Electricity consumption from electric vehicles (EV)

Definition

Estimated amount of electricity required to power EVs on the road, including battery electric and plug-in hybrids by vehicle type. We exclude fuel cell cars in our analysis.

Equation

Annual electricity demand from EVs = $\sum_{x=i}^{x} N_{x,y} * D_x * E_x$

Where

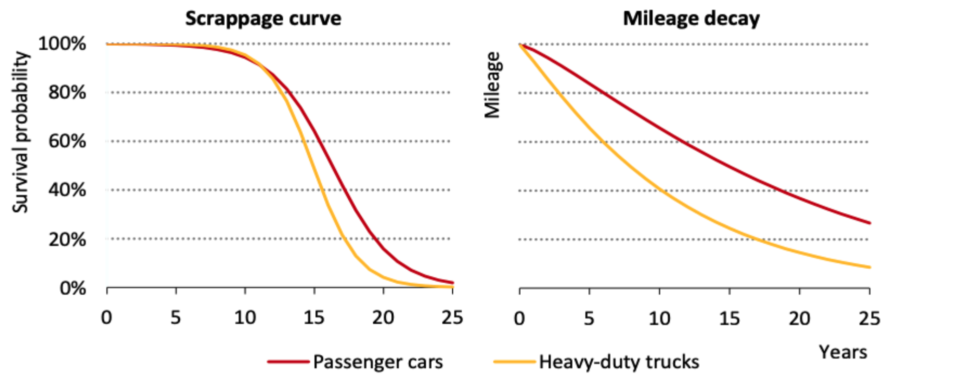
- x is the category of vehicles (Cars, Vans, Buses, Trucks),
- N is the number of EVs on the road,
- D is the average distance travelled per vehicle (km) by vehicle type and fuel type, weighted by average vehicle fleet of EVs.
- E is electricity required to drive 1 unit of distance, including charging loss (12%, source: Apostolaki-Iosifidou, Paul Codani, Willett Kempton (2017) and Reick et al. (2017)) (Watt-hour/km)

Data methodology

- EV stock and sales data
  - Estimating latest year data
- Average distance travelled per vehicle (D)

- Calculated by dividing the total annual traffic activity by (vehicle-km) by the total number of vehicles by vehicle type.
- Data quality of Eurostat data is inconsistent. For selected countries, we use data from the following sources:
- Mileage decay
    - Research has shown the annual distance travelled by a given vehicle diminishes over time. This concept is referred to as 'mileage decay', as defined by the IEA. This is particularly relevant for EVs since the fleet is relatively new.

Figure 3.5 ▹ Illustration of scrappage curve and mileage decay by vehicle type



- We need to split distance travelled by vehicle type and motor type, taking the mileage decay into consideration. Consider this equation: average age of all vehicle stock is the weighted average of the average age of EVs and ICE vehicles on the road. While there is no data on the average age of EVs, there is data on EV sales and the average age of total vehicle fleet. By assuming that EVs don't retire, we can work out roughly how old the current EV fleet is on average. Then, we can work out how old ICE cars are on average.

  We use the average age of EVs vs. ICE vehicles to weight vehicle stock of each category by the corresponding mileage decay rate, provided by the decay curve provided by the IEA (figure 3.5). Using the weighted stock number, we calculate the weighted average of the total vehicle-km by vehicle and motor types.

- Electricity required to drive 1 unit of distance
    - Vehicle fuel efficiency

        - For the United Kingdom, we use time-series estimates provided by the TAG data book, published by the Department of Transport.
        -
    - Charging loss (12%) is added to vehicle fuel efficiency. The % of energy lost during charging is from Apostolaki-Iosifidou, Paul Codani, Willett Kempton (2017) and Reick et al. (2017).

Primary Fossil Fuel Displacement

Definition

We calculate the amount of fossil fuel consumption that is avoided (displaced) by EVs on the road. It is the amount of fossil fuels that would have been necessary to drive the same distance driven by a battery electric car with a petroleum car, minus the primary fossil fuel input required to generate electricity needed to drive the same distance with an EV. This calculation only considers the energy consumption at operational level, meaning that it does not include the fossil fuel consumption required for manufacturing EVs.

Assumptions

- Battery electric vehicles have 89% average efficiency, including the gains from regenerative braking and charging loss (source: US EPA). This means energy loss within an EV is 11% of the total fuel (electricity) input.
- Internal combustion engine (ICE) cars have 20% average on average (source: US EPA). This means that energy loss within an ICE vehicle is 80% of the total fuel (petroleum) input.
- Plug-in hybrid cars' electric driving range is about 35% for EU countries and the UK (source: ICCT).
- 15% of primary crude oil is lost in the process of producing and transporting petroleum (source: Wang et al. (2008), as cited by SmartCitiesDive).

Equation

First, we calculate the primary fossil fuel consumption required to drive a unit of distance as an EV with an ICE car. All units are in MWh.

Useful energy consumed by an EV or ICE should be the same for driving the same distance. Useful energy is defined as the final energy multiplied by the efficiency of a vehicle. Then:

$UE_{EV} / UE_{ICE} = (FEC_{EV} * EFF_{EV}) / (FEC_{ICE} * EFF_{ICE})$

Where UE = useful energy, FEC = final energy consumption, and EFF = efficiency. From there, we can establish that:

$1 = (FEC_{EV} * EFF_{EV}) / (FEC_{ICE(equivalent)} * EFF_{ICE})$

Then we can solve for FEC_ice.

$FEC_{ICE\ (equivalent)} = FEC_{EV} * (EFF_{EV} / EFF_{ICE})$ — (a)

Then, we add the energy lost in the process of petroleum production and transportation (15%).

$PEC_{ICE(equivalent)} = FEC_{ICE(equivalent)} + FEC_{ICE(equivalent)} * 0.15$ — (b)

Second, we calculate the primary fossil fuel consumption required to drive an EV per km. This is given by:

$PEC_{EV} = EC_{EV} * PEC_{electricity}$ — (c)

Where PEC_electricity is primary fossil fuel input required to generate 1 unit of electricity, and EC is electricity consumption.

Thirdly, we subtract (c) from (b) to get fossil fuel displacement per km. All of the calculations above are done in MWh.

$PEC_{EV} = (FEC_{EV} * (EFF_{EV} / EFF_{ICE}) * 1.15) - (EC_{EV} * PEC_{electricity})$ — (d)

Finally, we multiply (d) by the number of vehicles on the road to get the aggregate fossil fuel displacement, both in GWh and barrels of oil using the conversion factor of 1GWh = 588.24 BOE

Emissions displaced

Definition

We calculate the amount of emissions avoided (displaced) by EVs on the road. It is the amount of emissions from burning primary fossil fuels that would have been necessary to drive the same distance driven by a battery electric car with a petroleum car, minus the emissions from burning primary fossil fuel input required to generate electricity needed to drive the same distance with an EV. This calculation only considers the energy consumption at operational level, meaning that it does not include the emissions from manufacturing EVs.

Equation

First, we apply the lifecycle emissions factor of burning mobile gasoline (304 kg/MWh) to (b), to get the emissions from burning primary fossil fuels that would have been necessary to drive the same distance driven by a battery electric car with a petroleum car (e). The emissions factor is from Edwards et al (2004)., as cited in Buberger et al (2022). Note that emissions from methane leakage are underestimated.

Second, we apply the emissions intensity factor of electricity to the electricity consumption of an EV (f).

Third, we subtract the (f) from (e), to get the emissions savings from driving an EV instead of an ICE car.

Data sources

Existing and new vehicle count by vehicle type, motor type

Geography	Category	Source
UK	Buses, Cars, Trucks, Vans	Department of Transport - VEH1103 for vehicle stock, - VEH1153 for new vehicles)
EU	Buses, Cars, Trucks, Vans	Eurostat ● Vehicle stock: - Road_eqs_carpda - Road_eqs_busmot - Road_eqs_lormot ● New vehicles: - Road_eqr_carpda - Road_eqr_busmot - Road_eqr_lormot

Total distance travelled by vehicle type

Geography	Category	Source
EU	Buses, Cars, Trucks	Eurostat - Road motor vehicle traffic performance by traffic and

		registration location and type of vehicle (in vehicle kilometres)
UK	Buses, Cars, Trucks, Vans	Road Traffic Statistics, Department for Transport - TRA0201: Road traffic (vehicle kilometres) by vehicle type in Great Britain

Electricity required to drive 1 unit of distance (Watt-hour/km)

For the UK, we use vehicle efficiency provided by the Department of Transport, via TAG data book.

EV type	Category	Source	Dataset	Time
EV	Cars	Electric Vehicle Database	Average energy consumption of full electric vehicles	2024
	Trucks	CENEX	The Battery Electric Truck Trial	2023
	Buses	Communications in Transportation Research	Jinhua Ji et al. (2022). Trip energy consumption estimation for electric buses	2022
PHEV	Cars	EPA, ICCT,	Share of driving in electric mode from REAL-WORLD USAGE OF PLUG-IN HYBRID VEHICLES IN EUROPE A 2022 UPDATE ON FUEL CONSUMPTION, ELECTRIC DRIVING, AND CO2 EMISSIONS	2024

https://ev-database.org/uk/cheatsheet/energy-consumption-electric-car

Reference: Vehicle category mapping

Across multiple sources

Ember (TBD)	**IEA EV tracker**	**Eurostat**	**UK Department of Transport**
	Cars	Passenger cars	Cars and Taxis
	Buses	Buses	Other Vehicles: Buses and Coaches
	Vans	Goods road motor vehicles less than 3.5 tonnes	Light Commercial Vehicles

	Trucks	Lorries, Goods road motor vehicles more than 3.5 tonnes	Heavy Goods Vehicles
	N/A	2-3 wheelers	Motorcyle

Eurostat fuel mapping

Eurostat fuel	**Eurostat code**	**Motor type**	**Fuel type**
Electricity	ELC	Electric	ELECTRICITY
Plug-in hybrid petrol-electric	ELC_PET_PI	Electric	PLUG-IN HYBRID
Plug-in hybrid diesel-electric	ELC_DIE_PI	Electric	PLUG-IN HYBRID
Liquefied petroleum gases (LPG)	LPG	ICE	LPG
Natural Gas	GAS	ICE	GAS
Petrol (excluding hybrids)	PET_X_HYB	ICE	PETROL
Hybrid electric-petrol	ELC_PET_HYB	ICE	PETROL_HYB
Diesel (excluding hybrids)	DIE_X_HYB	ICE	DIESEL
Hybrid diesel-electric	ELC_DIE_HYB	ICE	DIESEL_HYB
Biodiesel	BIODIE	ICE	BIO
Bioethanol	BIOETH	ICE	BIO
Bi-fuel	BIFUEL	ICE	BIO

Residential heating

Electricity consumption from heat pumps

Definition

Annual electricity required to meet the useful heat demand of households with heat pumps.

Equation

$$EC_{hp} = (UE_{household} / SCOP) * stock_{hp}$$

Where

- EC = electricity consumption,
- UE = useful energy demand for heating (water and space),
- SCOP = seasonable coefficient of performance, weighted by the ratio of water vs space heating,
- hp = heat pumps, assuming that one heat pump unit is for one household.

Let us explain how each variable in this equation has been derived.

1. Useful energy demand for heating per household

It is the final energy consumption for residential heating minus efficiency loss in the end-use application (ie. gas boiler). We simply multiply the average final energy consumption for residential heating per household by the efficiency factor for residential heating, which is derived from its fuel breakdown and boiler efficiency by fuel type.

$$UE_{heat/pp} = (FEC_{heat} / Household\ count) * EFF_{heating}$$

The data for final energy consumption is reported in TJ. We convert this to MWh by using the following conversion factor:

- 1TJ = 277.78 MWh

2. Seasonal coefficient of performance

It is the load-weighted average of COPs, with respect to the heating demand for water and space. It is derived from hourly heat demand data provided by Runau et al. (2023) For the last year, we carry forward previous year's value.

Primary Fossil Fuel Displacement

Definition

We calculate the amount of fossil fuel consumption that is avoided (displaced) by heat pumps. It is the amount of natural gas that would have been necessary to provide the useful heat demand per household, minus the fossil fuel required to generate electricity required to provide the same heat demand with heat pumps. This calculation only considers the energy consumption at operational level, meaning that it does not include the fossil fuel consumption required for manufacturing heat pumps.

Assumptions

- About 10% of total primary gas energy is lost during transformation and transportation for residential heating (source: Ulvestad and Overland (2012)).

Equation

First, let us consider the final fossil fuel consumption to meet the heating demand of a household. This is given by the data we collected for the final energy consumption for residential heating per household. Let us assume that this is all gas, because heat pumps are likely to be replacing gas boilers.

Second, we add the energy that is lost during transportation (10%) to get the primary fossil fuel consumption.

$PEC_{gas} = FEC_{heat/hh} * 1.1$ — (h)

Third, we calculate primary fossil fuels used to run a heat pump by multiplying the annual electricity demand for heat pumps from the previous calculation by emissions intensity of electricity. — (i)

Then, we subtract (i) from (h) to get fossil fuels displaced by heat pumps.

Finally, we multiply this result by the number of heat pumps in the market to get an aggregate figure.

Emissions displaced

Definition

We calculate the amount of emissions avoided (displaced) by heat pumps. It is the amount of emissions from burning primary fossil fuel (gas) to meet annual heating demand, minus the emissions from burning primary fossil fuel input required to generate electricity needed to run a heat pump. This calculation only considers the energy consumption at operational level, meaning that it does not include the emissions from manufacturing EVs.

Equation

First, we apply the lifecycle emissions factor of stationary natural gas combustion (201.96 kg/MWh) to (i), to get the emissions from burning primary fossil fuels that would have been necessary to meet the residential heating demand with a gas boiler. The emissions factor is from the Greenhouse Gas Protocol. Note that emissions from methane leakage are underestimated in this factor. — (j)

Second, we apply the emissions intensity factor of electricity to the electricity consumption of a heat pump (k).

Third, we subtract the (k) from (j), to get the emissions savings from using a heat pump.

Data sources

Heat pump stock and sales

Geography	Source
EU + UK	European Heat Pump Association

Final energy consumption for residential heating

Geography	Dataset
UK	Energy consumption by final user (energy supplied basis), 1970 to 2022 (DUKES 1.1.5) - The UK data source does not provide what percentage of the domestic energy consumption was for heating. - We use historical reporting to Eurostat until 2019 to interpolate missing data by calculating the historical average of % of heat in final energy consumption (76%) to the latest year's final energy consumption for the residential sector. The proportion of heat out of all domestic energy demand doesn't have much variance (75-78%).
EU	Eurostat • Nrg_d_hhq (with full fuel breakdown)

Number of households

Geography	Dataset

UK	Families and households statistics UK - For the latest year data, we carry forward the previous years' household number.
Eurostat	Number of Households (LFST_HHNHTYCH)

SCOP

Geography	Source
UK, EU	When2Heat