Can Electric Vehicles Contribute Significantly to Greenhouse Gas Reduction While Driving?

Electromobility
Environment & Energy BSc
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Contents of this Presentation

Can Electric Vehicles Contribute Significantly to Greenhouse Gas Reduction While Driving?

Why bother with the topic?

-What’s the Motivation?

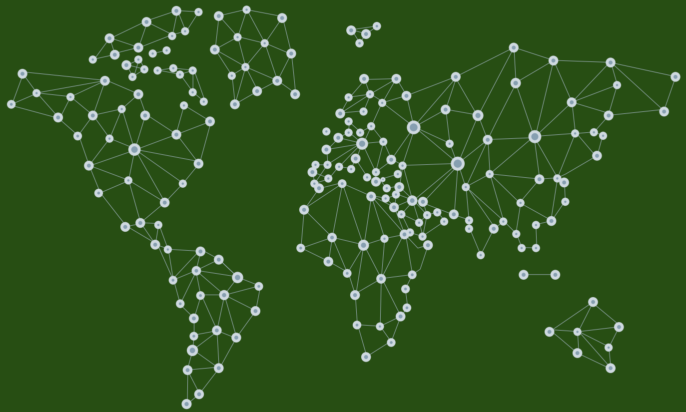
-What’s the Usefulness?

The Big Picture

- *CO_2 levels on the rise*
- *NDCs*
- *Transitioning Mobility Industry*

…. Can Battery Electric Vehicles (BEVs) really lower GHG emissions?

State of the Industry



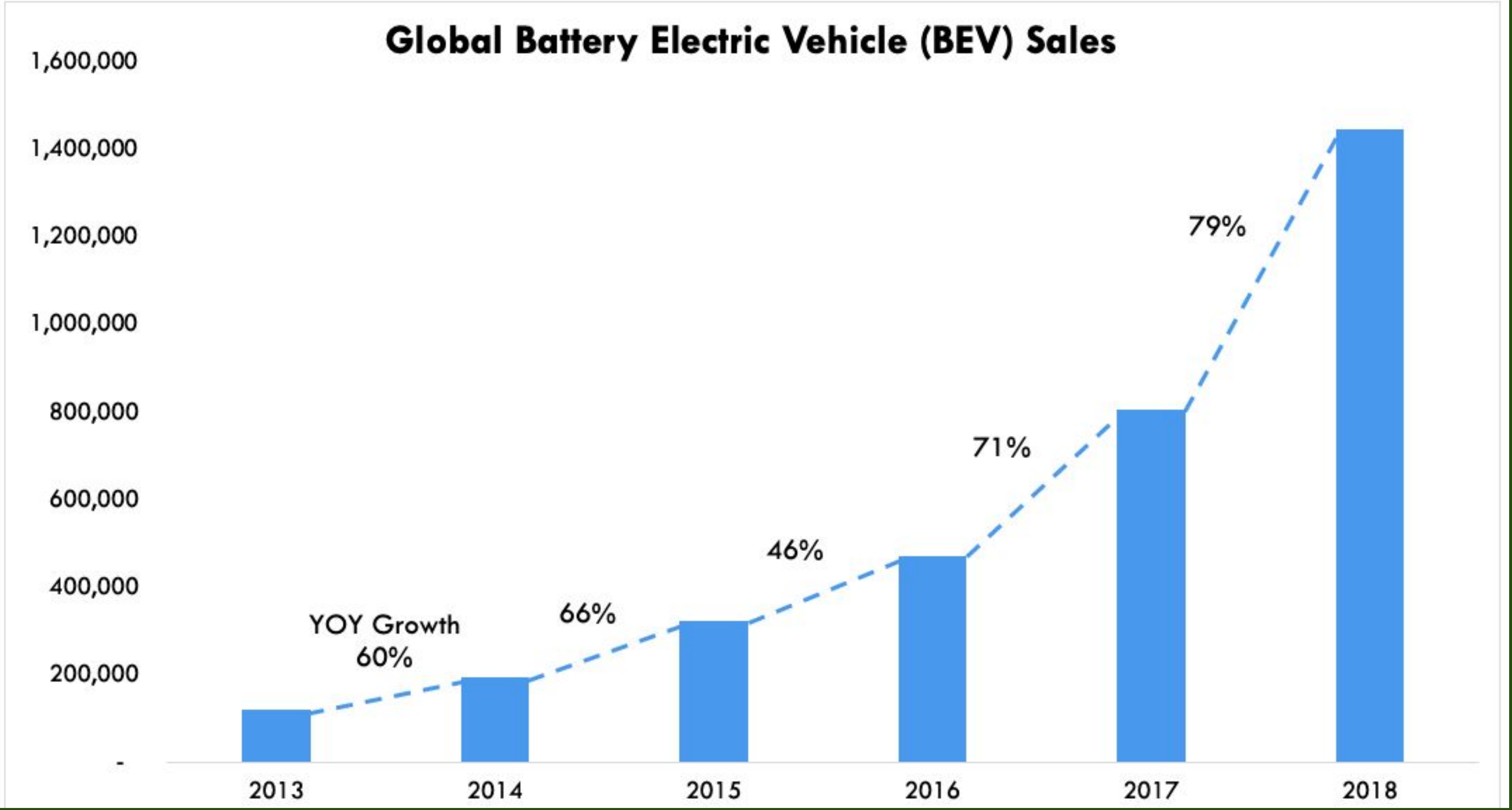


Fig. 1.0 Global BEV Sales, taken from Korus S. (2019)

BEV Propulsion

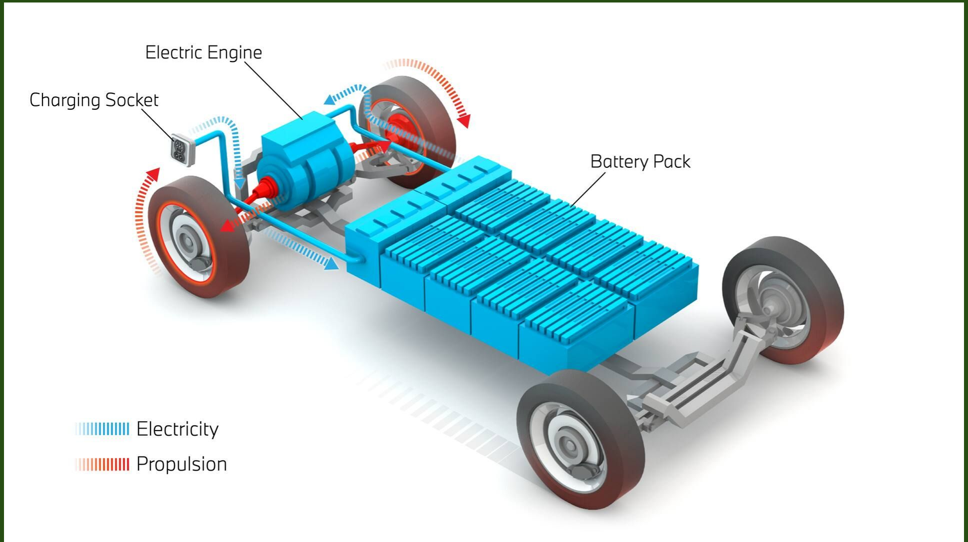


Fig. 2.0 Simplified Propulsion in Battery Electric Vehicles (BEVs), taken from BMW (2019)

Important Components:

- Battery pack
- Electric Motor
- Inverter
- Controller
- Charging cable
- etc.

ICEV Propulsion

Fuel + Oxygen → Carbon Dioxide + Water

Eq. 1.0: Simplified equation of combustion of fuels in ICEVs

During the use phase, ICEVs will emit increasing CO_2 emissions proportional to their fuel use.

Key points:

- Petrol/Diesel combusted
- Pistons move linearly
- Linearly momentum converted to circular momentum in the gears
- Gears connected to driveshaft, and driveshaft to the wheels for

Movement achieved!

Comparing BEVS and ICEVs

LCAs for comparison, a tool to deduce related GHG emissions.

LCA Comparisons

BEVs

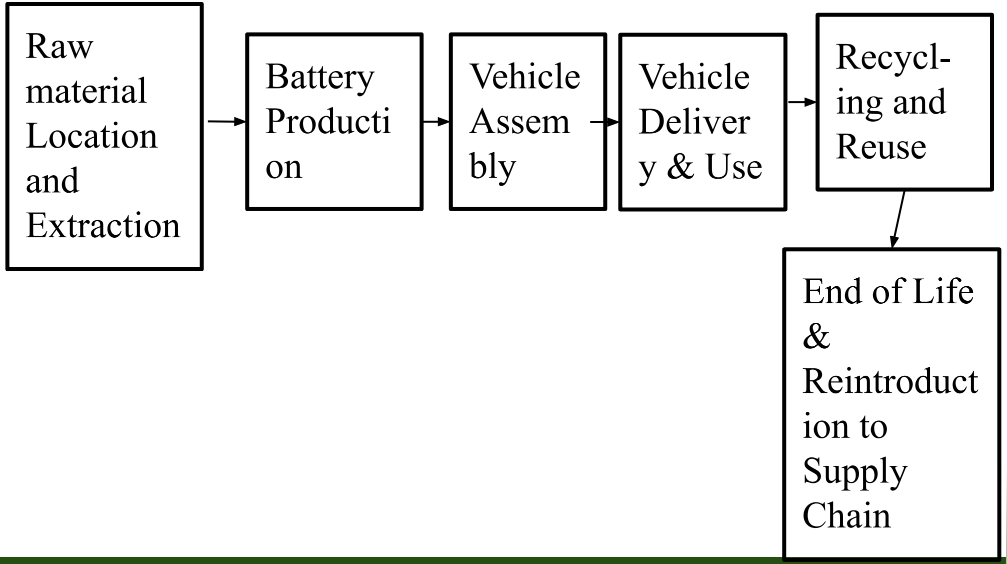


Fig.3.1 Simplified stages of the life cycle of an electric vehicle.

ICEVs

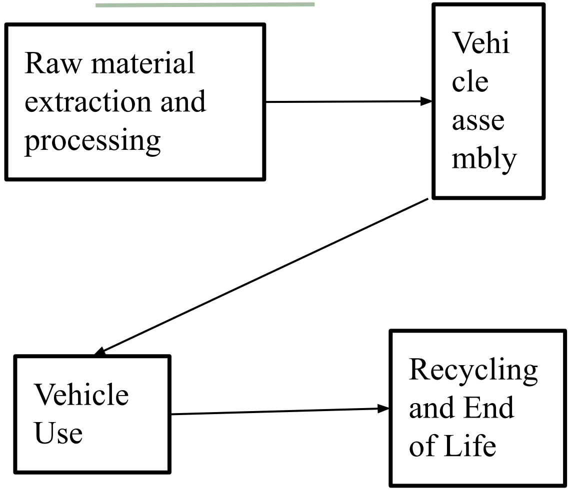


Fig 3.2 Simplified LCA of an ICEV

Differences Occur. But why?

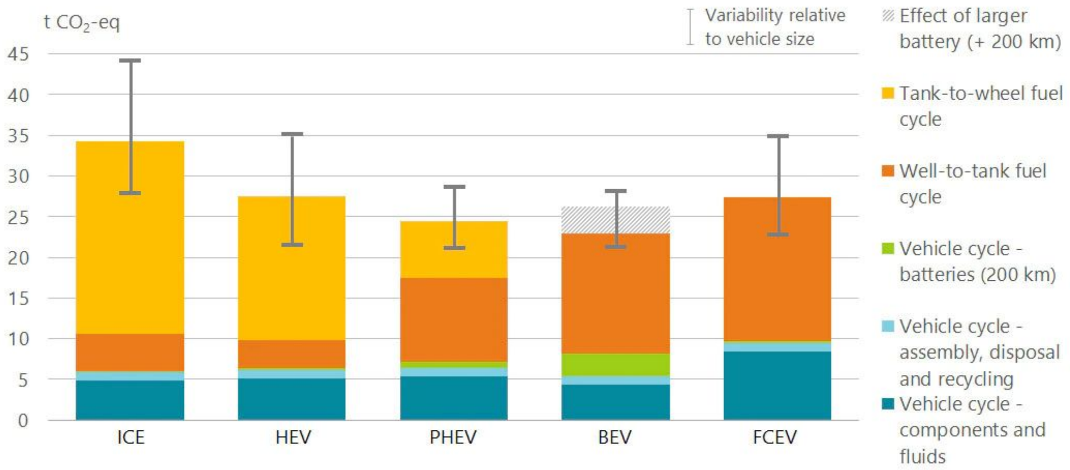


Fig. 4 The tonnes of CO_2 equivalent emitted at different stages of use for vehicle types: Internal Combustion Engine (ICE), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), Battery Electric Vehicle (BEV) and Fuel Cell Electric Vehicle (FCEV).

Source: IEA (2019)

-This figure portrays mid-size vehicles having similar performance with the exception of driving range. BEV has 200 km range, the shaded area refers to a vehicle with 400 km range.
-The ranges suggested by the sensitivity bars represent the case of small cars (lower bound) and of large cars (upper bound).
-The carbon intensity of the electricity mix is assumed equal to the global average (518 g CO2/kWh).
-FCEVs are assumed to rely entirely on hydrogen produced from steam methane reforming.

Which Stages of the LCAs are most important to consider as it relates to carbon dioxide ?

Production without Battery

- 6t CO_2 equivalents for ICEVs
- 5t CO_2 equivalents BEV

Battery Production

- 0t CO_2 equivalents for ICEV
- 3-4t CO_2 equivalents for BEV.

Use Phase: Well to tank cycle

- 24t CO_2 equivalents for ICEVs
- 15t CO_2 equivalents for BEVs

- Values taken from IEA (2019)

Impact of Source of Electricity & Energy Mix

- Highest CO_2 emissions occur when coal is the energy source (~1050g CO_2/kWh)
- When renewable sources are used, the emissions are less than 70g CO_2/kWh

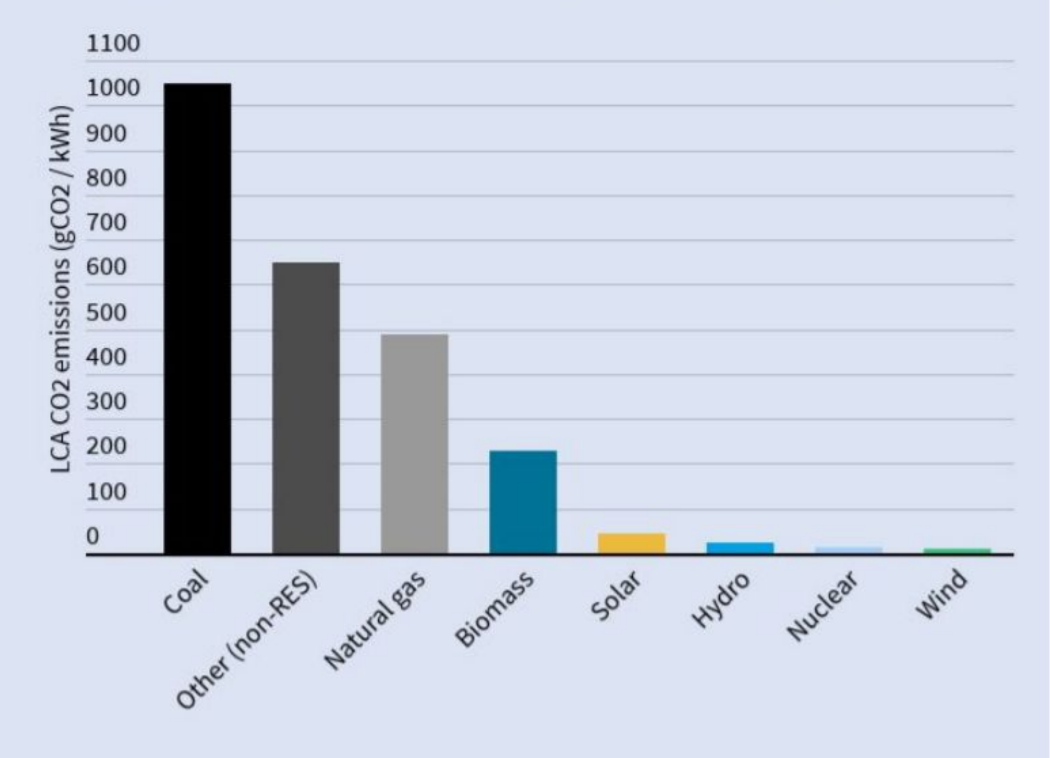


Fig.5.0 Life-cycle intensity of CO_2 of different sources of electricity (T&E, 2020)

Note: Emission of plant construction and decommissioning are considered.

How does the situation look in Germany?

Any guesses?

Production

Capacity

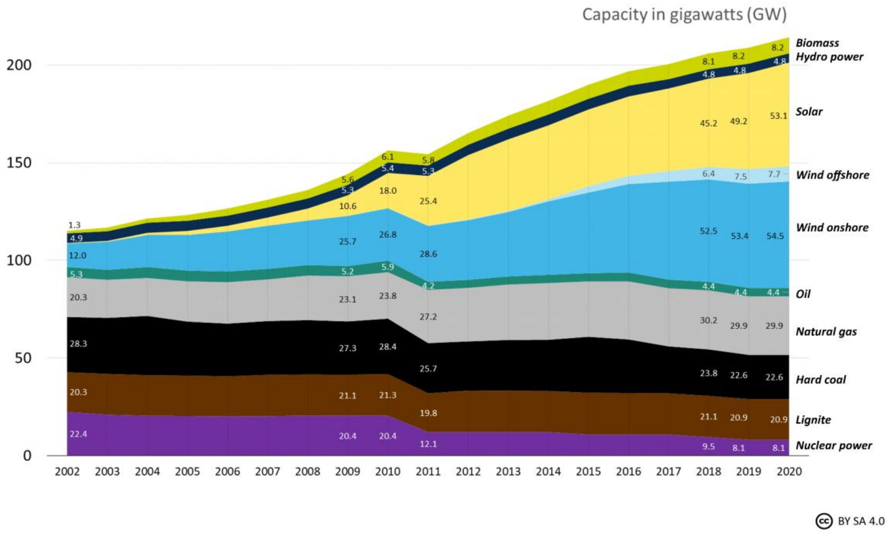


Fig 6.1 Installed net power capacity of Germany (Appunn et al, 2021).

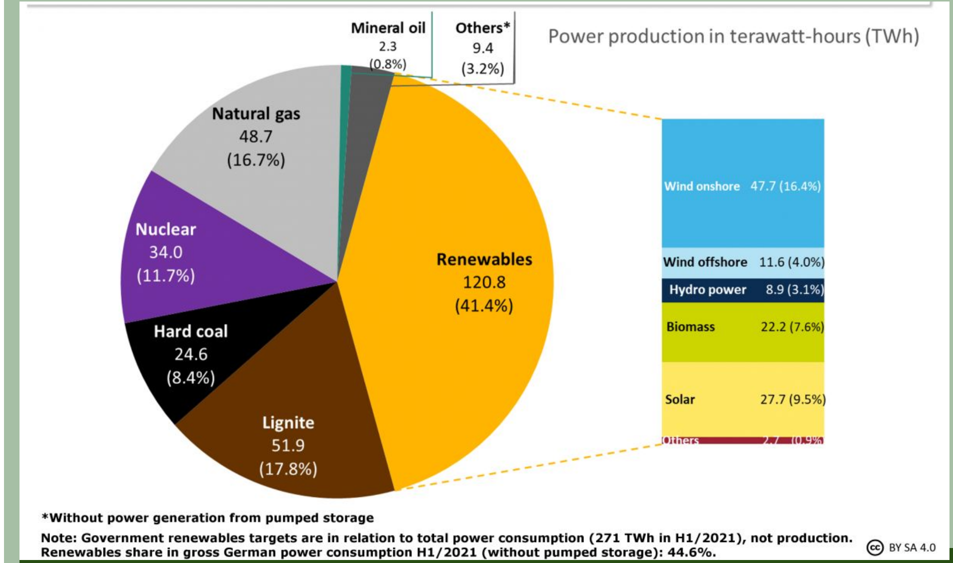


Fig.6.2 Share of energy sources in gross German power production during the first half of 2021 (Appunn et al, 2021).

Production

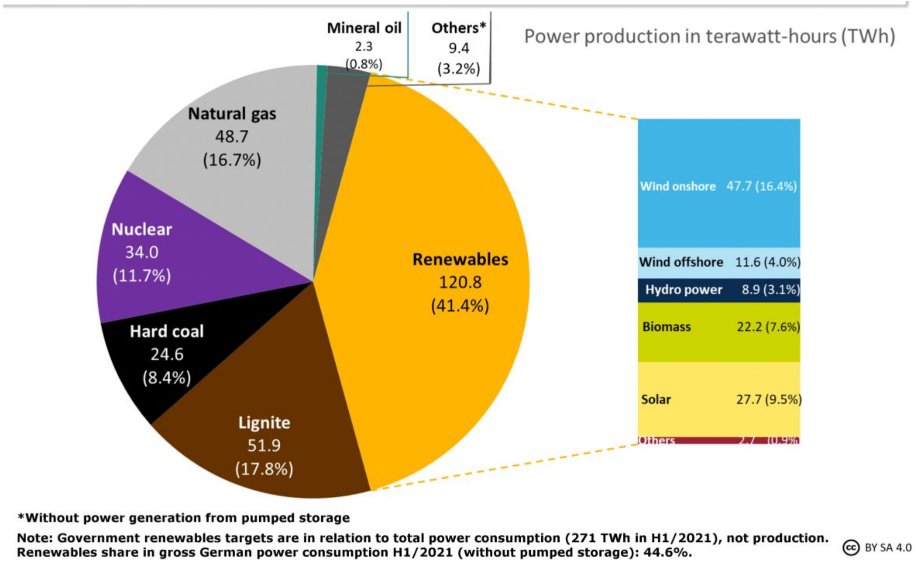


Fig. 6.3 Share of energy sources in gross German power production during the first half of 2021 (Appunn et al, 2021).

Consumption

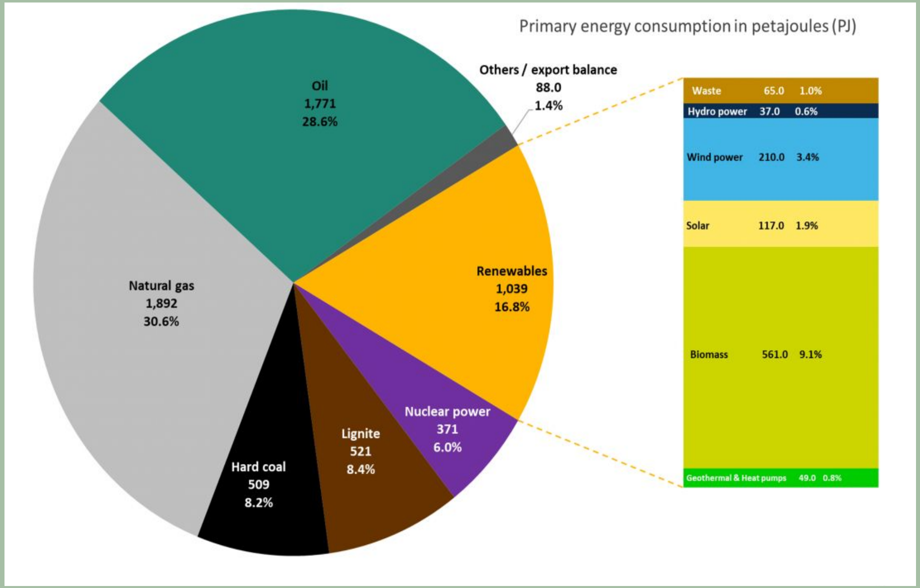


Fig 6.4 Energy sources' share in primary energy consumption in first half of 2021, Germany. (Appunn et al, 2021)

Energy mix; Capacity and Production differences in Germany.

- Despite having a power generation capacity of 120GWh from renewable sources (excluding biomass), the actual share of electricity used from renewable resources is 251.1 TWh.

- From 120 GWh capacity, 1052.08 TWh of production is possible for the year.

- That therefore represents a 23% utilization of the renewable electricity production capacity!

  For reference: Nuclear = 90.6%, Lignite = 50% utilization from capacity.

  *This calculation is derived independently using data from from Appun et al (2021)

Percentage utilization from Total Capacity

23%

For renewables

90.6%

For nuclear energy

Energy mix; different points of the year.

CO_2-Emissionen im Strommix [g CO_2 je kWh]

Quelle: EUPD Research 2021

	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
00:00	349	227	297	294	314	362	408	413	450	368	433	396
01:00	346	222	293	287	305	348	399	401	443	362	429	390
02:00	342	217	293	284	301	341	390	393	438	352	425	387
03:00	341	216	290	284	302	340	385	393	437	359	426	385
04:00	343	220	297	290	306	344	386	399	442	368	430	388
05:00	355	232	310	301	319	357	393	414	455	389	441	400
06:00	367	247	322	304	318	360	389	421	464	407	451	414
07:00	373	253	311	288	295	342	360	403	449	407	450	418
08:00	374	253	290	263	268	318	327	373	419	400	440	419
09:00	367	247	273	235	242	294	296	346	393	386	430	416
10:00	359	239	253	203	216	274	273	322	366	372	420	410
11:00	354	232	240	183	200	259	257	302	341	361	412	407
12:00	350	229	235	172	192	250	247	291	324	351	412	409
13:00	353	228	238	167	189	245	242	288	315	349	424	419
14:00	364	233	246	168	189	245	242	292	320	356	444	431
15:00	380	244	263	176	197	251	250	306	340	374	469	437
16:00	389	258	292	198	210	265	269	328	377	398	476	429
17:00	379	264	323	239	240	288	300	360	420	413	460	417
18:00	373	260	335	279	276	320	333	390	454	411	454	418
19:00	372	259	333	301	305	352	364	414	462	404	456	421
20:00	368	254	330	306	324	376	393	427	462	400	460	422
21:00	363	246	326	307	332	388	409	431	468	394	456	418
22:00	359	243	323	305	333	386	413	432	468	386	454	416
23:00	351	235	316	296	326	383	417	432	457	373	448	409

Fig. 7 Emissions of CO_2 from the energy mix at different times of the year in Germany. (EUPD, 2021).

- February was the month with the most favorable conditions for wind power, as a result CO_2 emissions for this time are lower compared to January and March.
- Notice the difference between daytime and night time emissions in the summer; 247-417 g carbon dioxide per kWh!

Vehicle and Battery Production; Carbon Footprint

Vehicle and Battery Production; Carbon Footprint

- ICEV and BEV production (without battery) emissions are relatively similar at the beginning of their lifetime (IEA, 2019).

- When it comes to manufacturing eco-efficiency, a high production capacity and an electricity mix with low carbon intensity are important in lowering the carbon intensity of battery production. Therefore, the Energy mix plays a large role again in battery production emissions!
- The economies of scale are smaller for bigger plants. Doubling the plant capacity from 17.4 GWh per year to 35 GWh per year only reduces the GHG emissions by 6% (Philippot et al, 2019). Therefore, bigger operations tend to me slightly less carbon intensive.

- The process is further improved by reducing the electricity consumption during the manufacturing and combining it with higher pack energy density. Done by increasing the number of cells per volume.

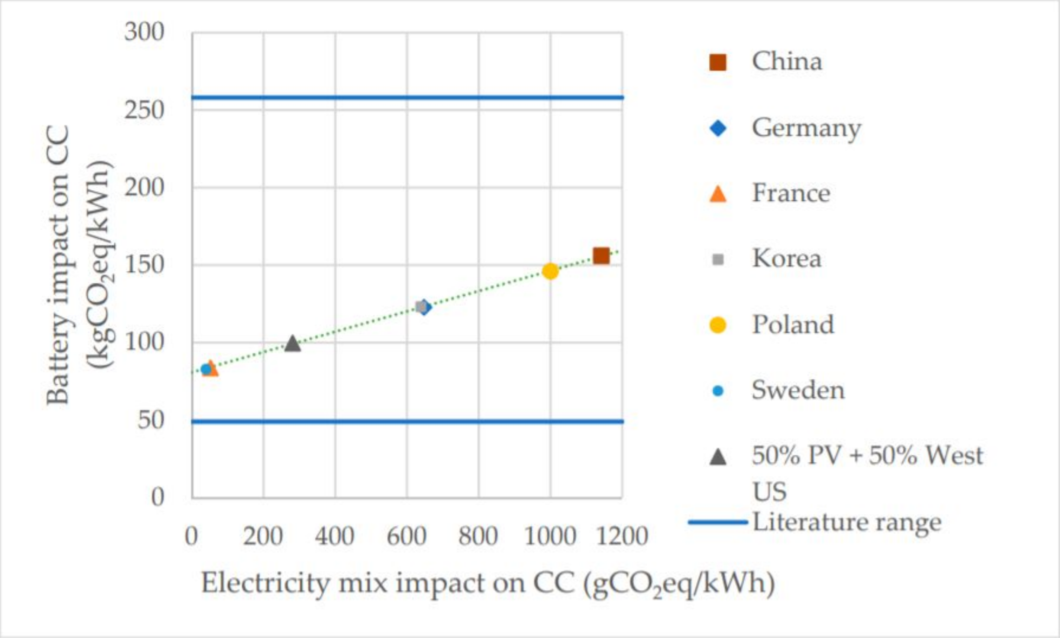
Vehicle and Battery Production; Carbon Footprint

Table 1: GHG Emission of a battery pack manufactured at Different Scales (adapted from Philippot et al (2019)).

Annual Cell Production (cells)	7×10^7	1×10^8	5×10^8	1×10^9	2×10^9
Impact of GHG emissions (kg CO2 eq/kWh)	168	157	123	114	107

- At larger production quantities GHG reduces per kWh.

GHG emissions for battery production a different energy Mixes.



- **Countries with lower carbon-intensity grids have lower battery production emissions.**

Fig 8.0 Carbon dioxide equivalent emissions per kWh emitted for a battery pack manufactured in different countries with different energy mixes (Philippot, 2019)

Key points to Reduce GHG during Battery Production

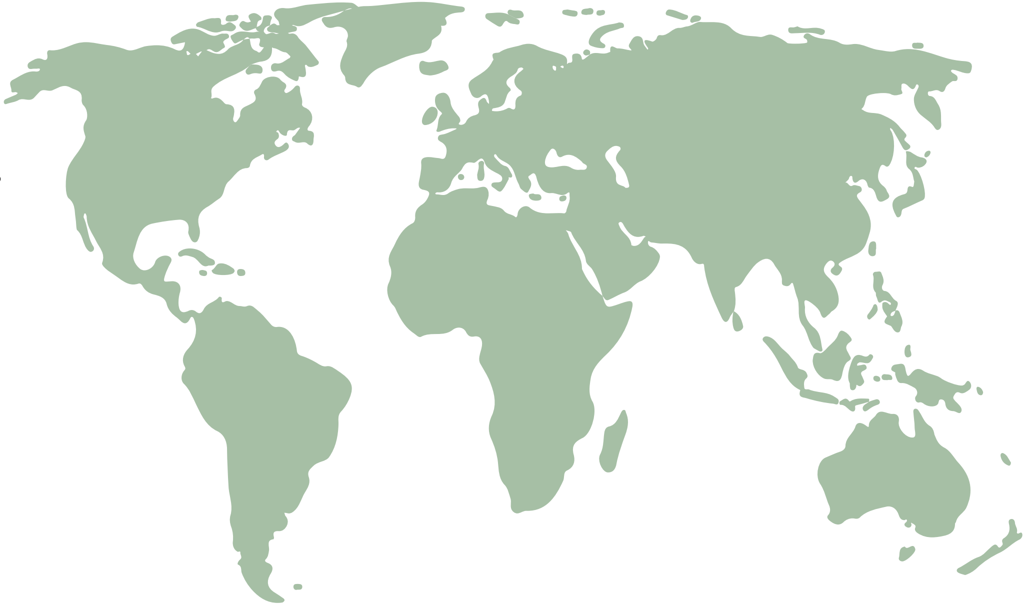
Increase Production Volume (number of cells per factory).

Use electricity mix with low carbon intensity.

Increase energy density of the cells

Afterlife and Recycling of Batteries

How can traction batteries be reused and repurposed?



Afterlife and Recycling of Batteries

- Traction batteries can be repurposed as storage options to stabilize home.

- stabilize grid electricity use and consumption.

- Recycling and reutilization of parts in earlier steps of the life cycle.

Afterlife and Recycling of Batteries

For 2020 minimum values of 87g CO_2 per kWh were recorded, and a maximum of 664g CO_2/ kWh (EUPD, 2021)

- Difference of 557g CO_2/ kWh during 2020.
- Poor grid management and energy utilization can be almost x10 more carbon intensive, even when the capacity is there!

Overall Assessment & Conclusion

The Bottom Line.

What we've learned so far...

- The CO_2 impact of BEVs is significantly high during battery production.

- The use of renewable energy in the energy mix alludes to the carbon intensity during the use phase of BEVs.

- The ability of the grid to utilize full renewable energy capacity is important in CO_2 emissions.

- Both battery production emissions and driving emissions, which are the most carbon intensive stages of BEV's life cycle, are highly dependent on the energy mix of the country.

The Bottom Line

How do varying carbon intensities compare in the mobility industry?

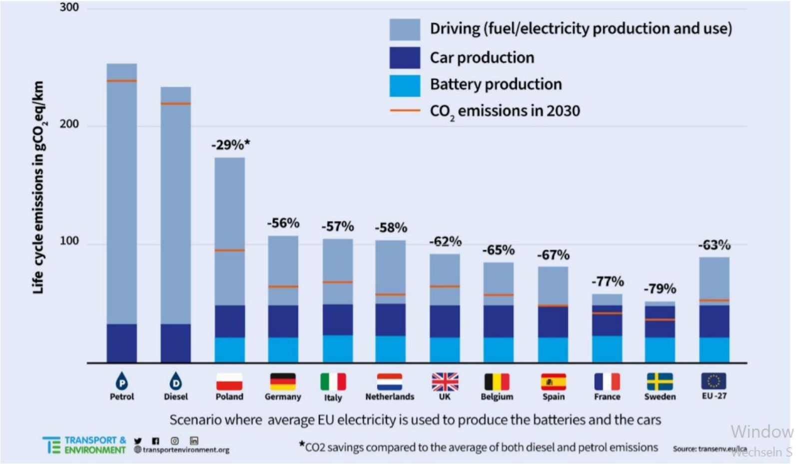


Fig 9.1 Lifetime Carbon dioxide emissions from BEVs, petrol and diesel car from different energy mixes in the EU (T&E, 2020)

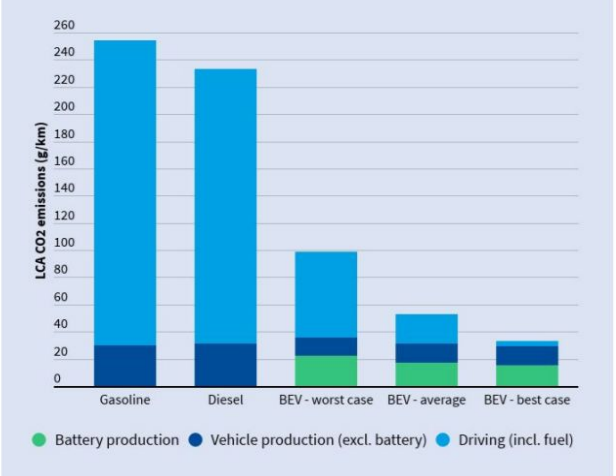


Fig. 9.2 Lifetime CO_2 emissions of an electric car, compared to diesel and petrol cars, in 2030 (T&E, 2020).

Deductions

Figure 9.1 shows the emissions which can be saved depending on different energy mixes in the EU, compared to the diesel and petrol averages. Even in countries where renewables comprise a smaller portion of the energy mix and electricity use (Poland and Germany) BEVs still emit less carbon dioxide equivalents than the petrol and diesel counterparts over the course of their lifetime use.

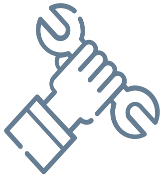
Diesel and petrol cars emit almost 3 times as much CO_2 equivalents over the course of their lifetime, despite the less complicated LCA in Figures 3.1 and 3.2.

Clear to see is, even in the worst cases BEVs outperform ICEV models substantially.

“When charged with electricity of a carbon intensity of 467 g CO_2 equivalents/kWh (which resembles the carbon intensity of the electricity mix in the EU in 2008), a reference electric vehicle is associated with a well-to-tank carbon intensity of 60–76 g CO_2 equivalents/km,” (Helmer & Weiss, 2017).

- reinforces, findings presented by T&E (2020).

Conclusions



- Lifecycle carbon footprint of BEVs tends to be most intensive due to the electricity mix used in battery production factories and when recharging the car (Philippot et al., 2019).

- Even for the most CO_2 intensive grids in the EU, BEVs still contribute less to CO_2 emissions than ICEVs (T&E, 2020)

- Lastly, not only can BEVs contribute to less GHG emissions, their afterlife potential as storage systems helps develop grid management techniques for non-renewable electricity to be utilized more efficiently in the grid.

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Thanks!

Do you have any questions?

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