Modelling the transport sector's CO_2 emissions in Germany: Background information and a practical example

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SUMBA+ Webinars

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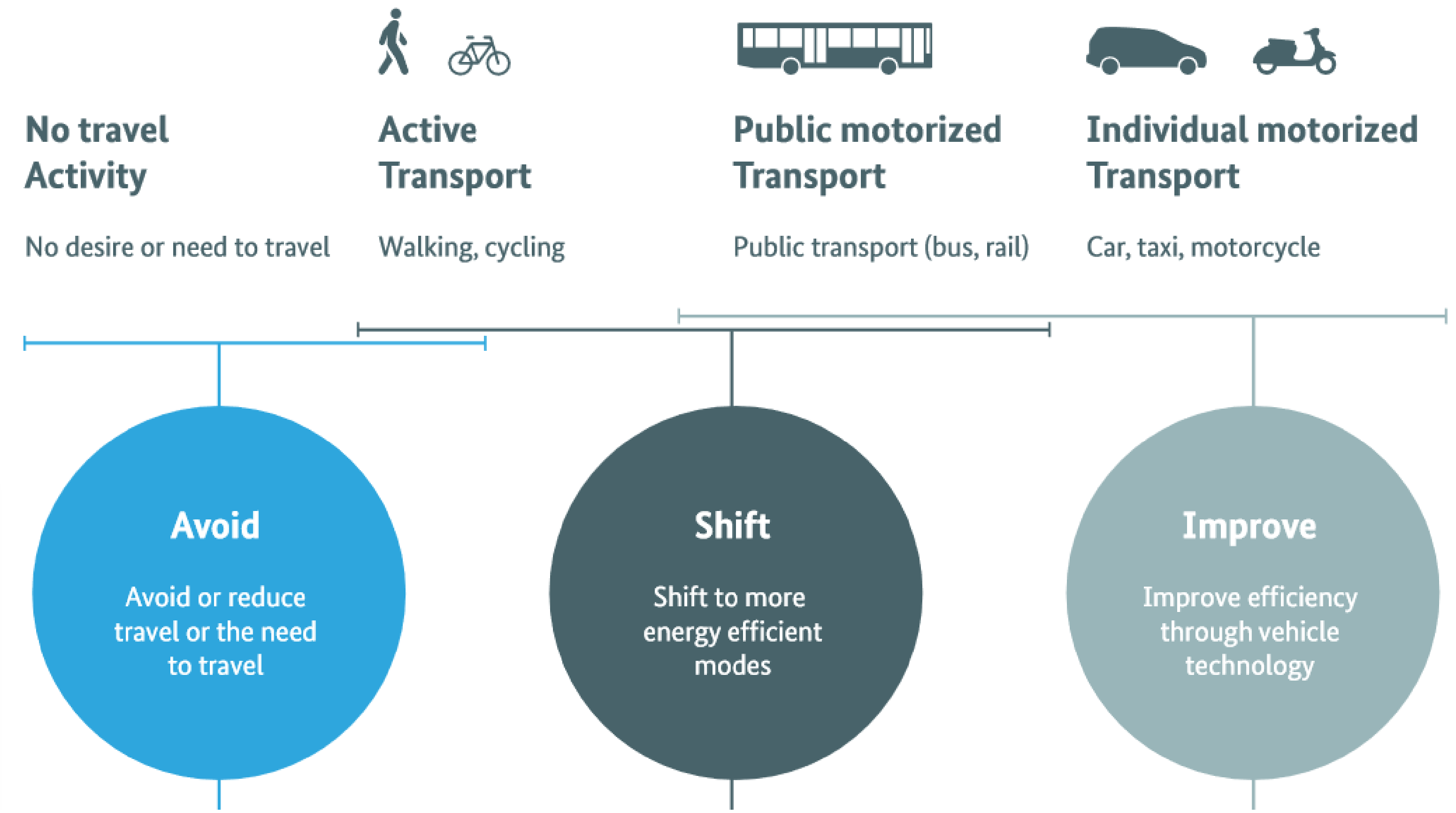
DLR

Avoid-Shift-Improve: The three pillars of reducing the climate impact of the transport sector



Source: GIZ (2019).

The burning of fossil fuels in road transport, aviation, navigation and rail transport releases greenhouse gases

- The burning of fossil fuels inside internal combustion engines releases greenhouse gases (and various types of pollutants).

- CO_2 is the dominating greenhouse gas within the transport sector (Germany 2019: ~99% of CO_2 equivalents).

- Road transport is responsible for almost the entire CO_2 equivalents in Germany (2019: ~97%), the rest is accounted for by domestic aviation, domestic navigation, and rail transport.

Source: Umweltbundesamt.

A vehicle's CO_2 emissions depend directly on its fuel consumption

- A vehicle's CO_2 emissions depend directly on its fuel consumption: Burning one liter of gasoline releases 2.33 kg CO_2, one liter of diesel 2.65 kg CO_2. No catalytic converter and no filter will help!

- CO_2 emissions of the transport sector refer to real driving consumptions and not to standardized test cycles like the WLTC, which is applied for type approval of new passenger cars.

- Through CO_2 emissions standards the EU regulates average test cycle consumptions of newly registered vehicles (2021 NEDC: 95 g/km for cars → ~4.1 liters/100km for a gasoline car). Today, emission standards are a powerful instrument stimulating the diffusion of zero emission vehicles.

Source: Umweltbundesamt.

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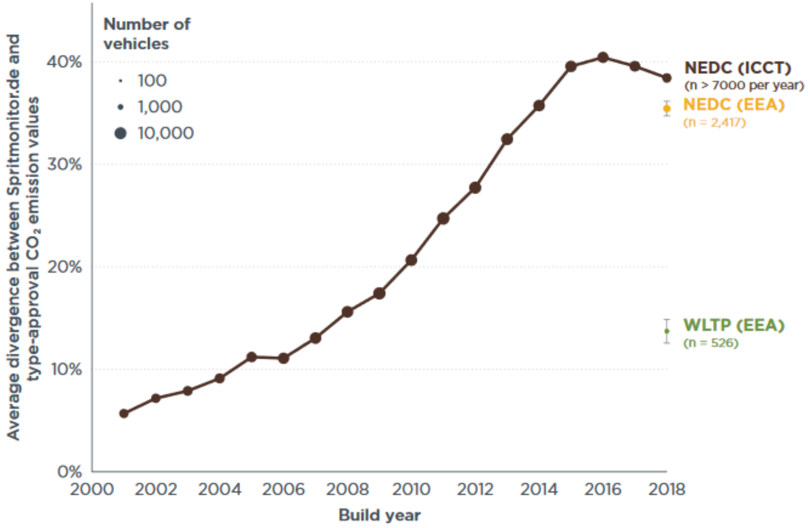


ICCT (2020): On the way to "Real-world" CO_2 values: The European passenger car market in its first year after introducing the WLTP

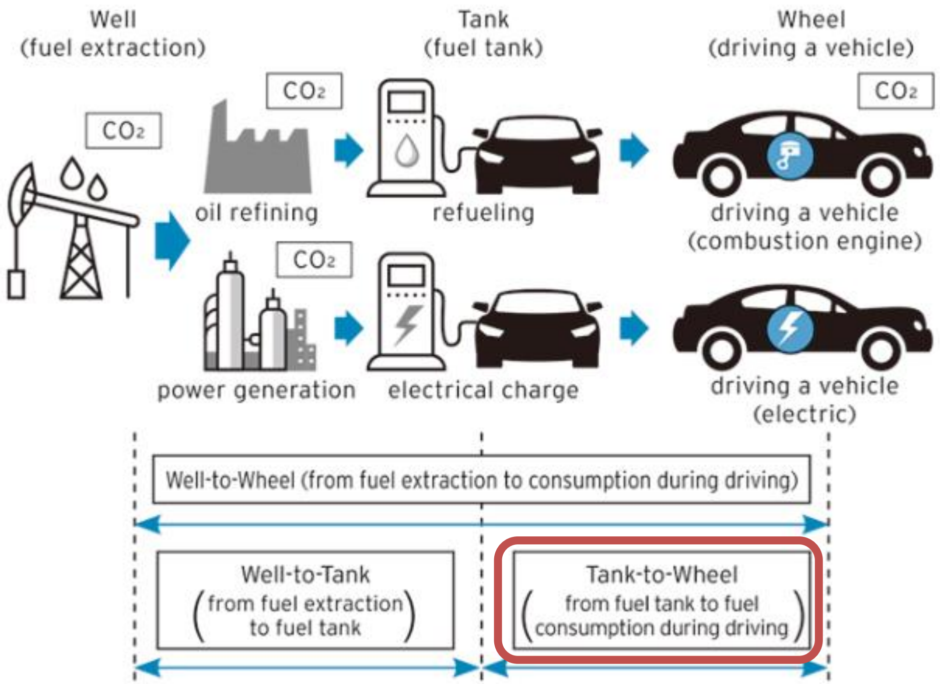
The transport sector's CO_2 emissions refer to tank-to-wheel emissions

- CO_2 emissions of the transport sector refer to a subrange in the energy chain of a vehicle that extends from the point at which energy is absorbed to discharge, i.e. Tank-to-Wheel (TTW).

- Under the TTW perspective and concerning CO_2 emissions battery electric vehicles (BEV) and hydrogen-powered fuel cell electric vehicles (FCEV) are zero emission vehicles.

- The Well-to-Wheel perspective covers the entire energy consumption and CO_2 emissions of a fuel caused by production, supply and use.

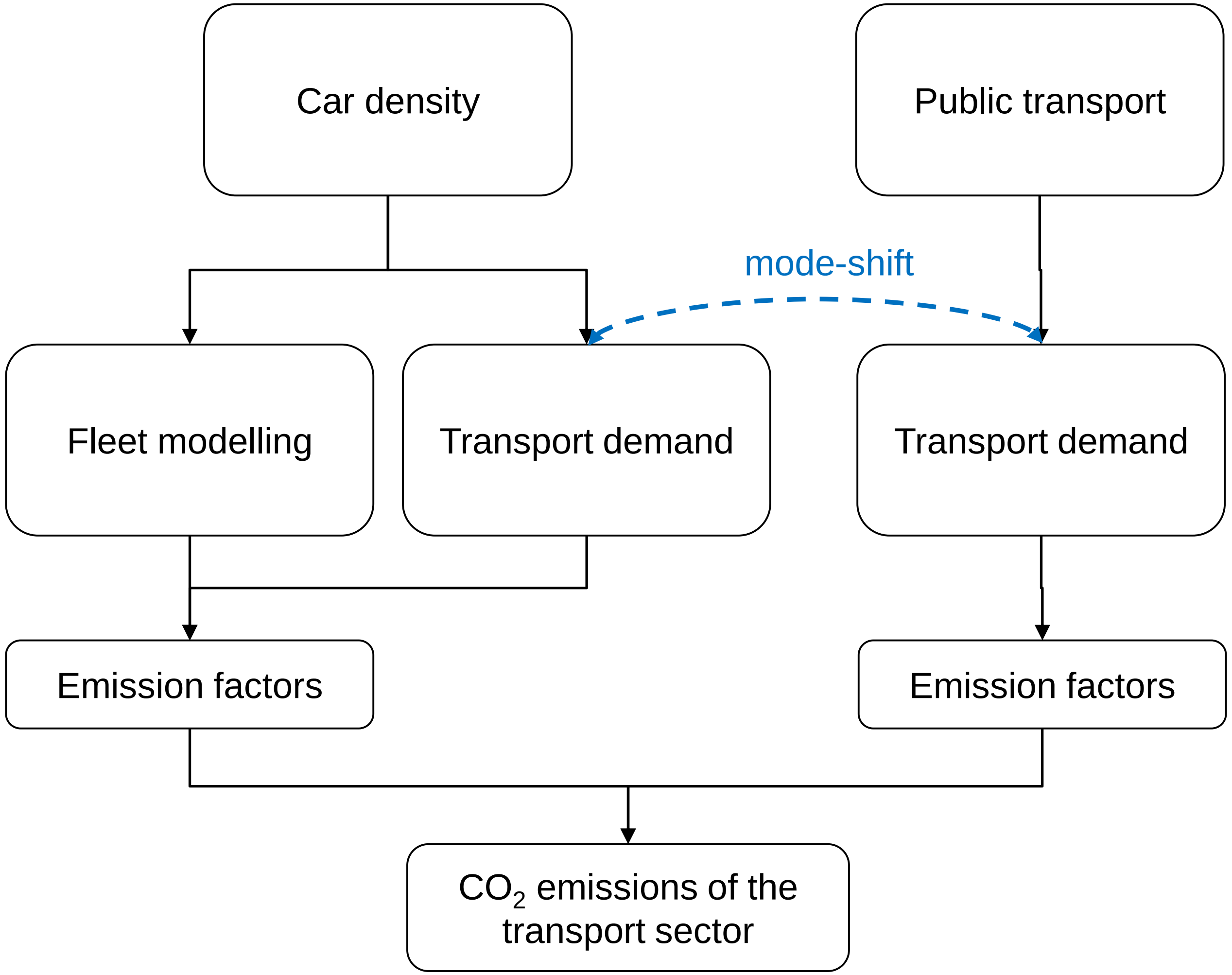
- Life cycle assessment (LCA) covers all stages of the life cycle of a vehicle (cradle-to-grave), i.e. Well-to-Wheel + vehicle body cycle (manufacture, maintenance, recycle).



https://www.mazda.com/en/csr/special/2016_01/

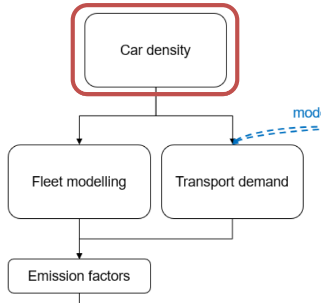
Source: Sacchi et al., Zheng & Peng (2021).

Modelling CO_2 emissions of passenger transport relies on a number of models and assumptions

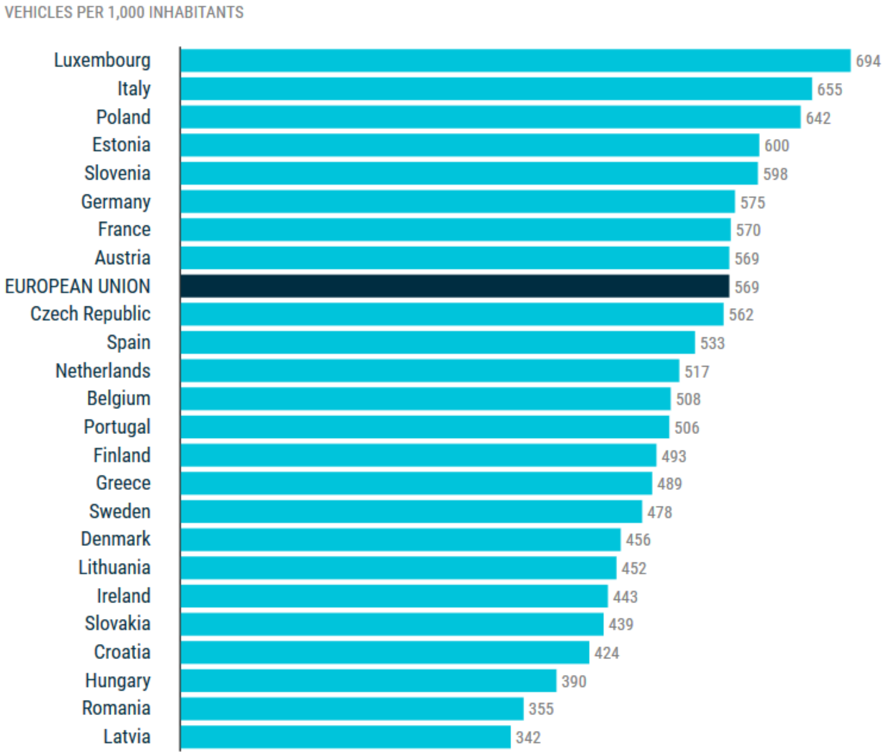


Assessing the CO_2 emissions from individual transport

Assessing the CO_2 emissions from individual transport | Car density



- Car density refers to the number of cars standardized by the population of a country/region/city.
- In Germany, car density has been increasing steadily and reached 575 cars per 1,000 inhabitants in 2020.
- Car density in cities is typically lower than in rural settings.
- Car density of a country is typically estimated as a function of economic development.
- Assessing the effect of measures on car density can be challenging and often relies on assumptions based on literature or case studies.



https://www.acea.auto/figure/motorisation-rates-in-the-eu-by-country-and-vehicle-type/

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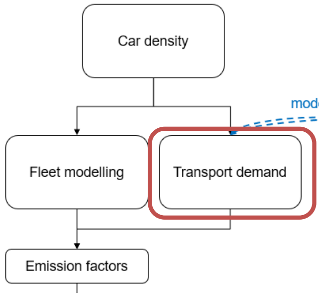
Assessing the CO_2 emissions from individual transport | Transport demand

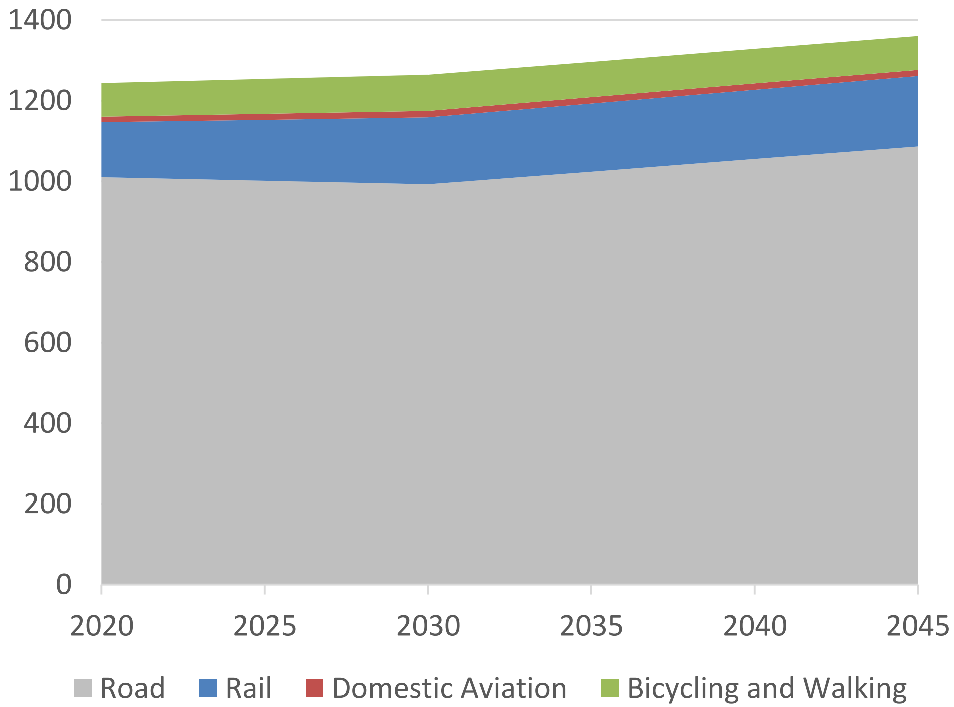


- Transport demand models estimate the total number of trips, the trip distance and the mode choice.

- Inputs are a spatially differentiated population (age groups, employment, car density) and transport supply parameters (travel times and costs per transport mode).

- Important outputs are the total number of trips and the transport demand for every mode which is spatially disaggregated to individual streets.

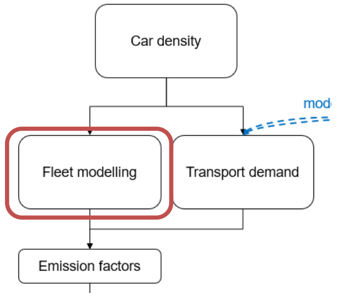
- Open source **T**ravel **A**ctivity **Pa**ttern **S**imulation (TAPAS) provides data on the future development of passenger transport demand in urban areas (https://github.com/DLR-VF/TAPAS).



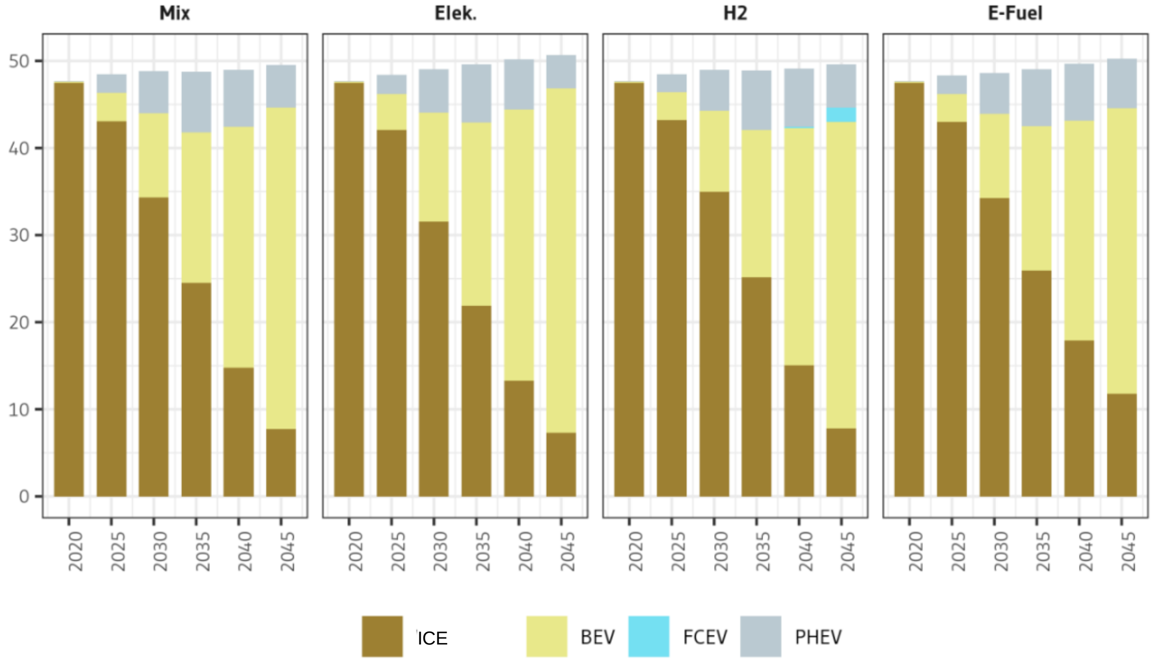
On the basis of https://ariadneprojekt.de/media/2021/10/Ariadne_Szenarienreport_Oktober2021.pdf

Assessing the CO_2 emissions from individual transport | Fleet modelling

- Fleet modelling serves to forecast the future (car) fleet.
- Fleet models differentiate between powertrains (e.g. gasoline, hybrid, BEV) and between segments (small, medium, large).
- Inputs are various vehicle and demand specific factors (yearly mileage, number of household members, investment and usage cost) and general conditions (charging infrastructure, CO_2 standards).
- The output is the future car fleet that is differentiated by powertrains and segments for a given set of conditions (e.g. technological development).



Car stock in four scenarios [million]



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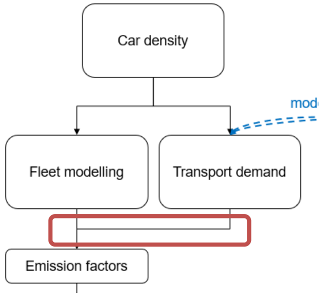
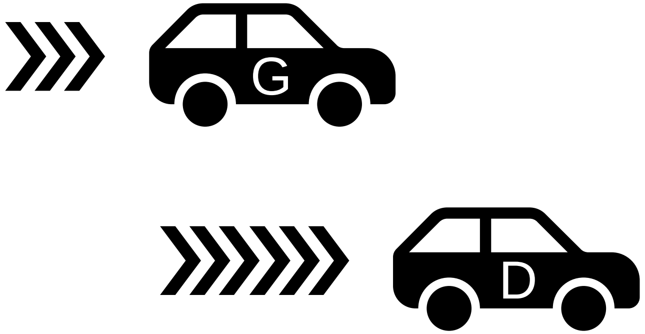
Assessing the CO_2 emissions from individual transport | Towards emission factors



- To calculate the total CO_2 emissions from individual transport the passenger kilometers have to be transformed to vehicle kilometers (assumption on car utilization).

- For cars, stock shares do not represent vehicle kilometer shares. A weighting of the different powertrains accounts for different annual mileages (e.g. diesel cars cover more kilometers per year than gasoline cars).

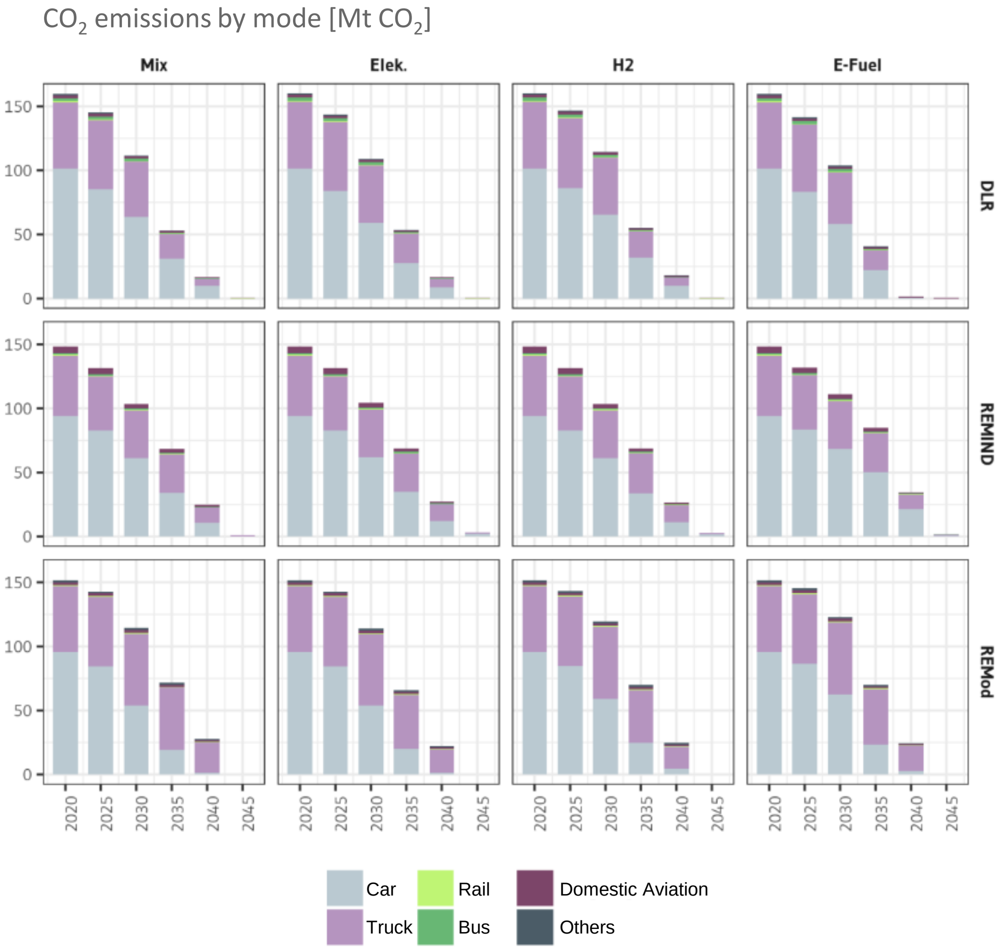


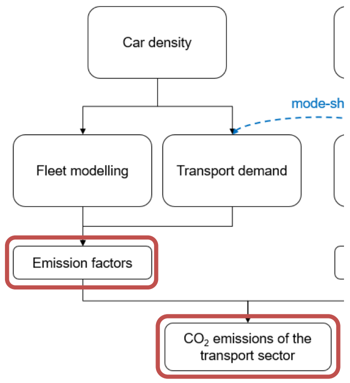
Assessing the CO_2 emissions from individual transport | Multiplying vehicle kilometers by emission factors

- Finally, vehicle kilometers by powertrains are multiplied by the respective emission factor to get the total CO_2 emissions from individual transport in a specific year.

$$x\ km_{Diesel,t} * y\ \frac{g\ CO_2}{km}_{Diesel,t} = z\ gCO_{2\,Diesel,t}$$

- Note: The blending of biofuels or e-fuels reduces fossil CO2 emissions.



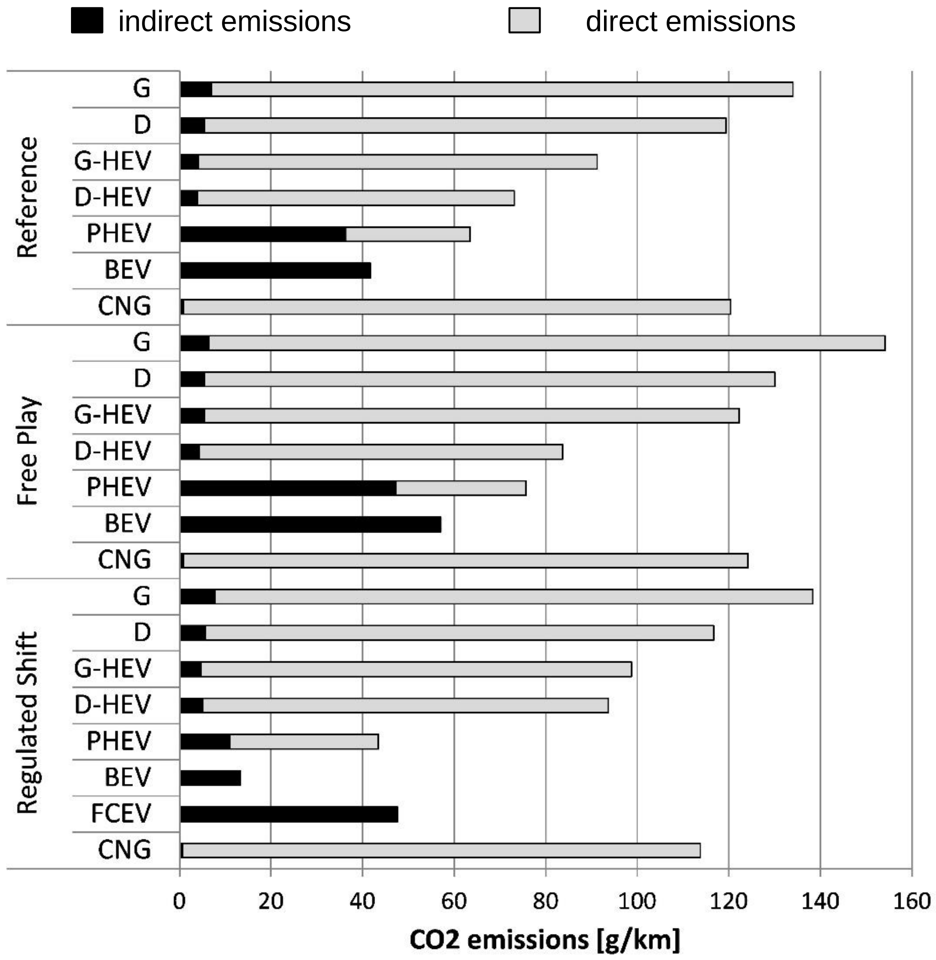


On the basis of https://ariadneprojekt.de/media/2021/10/Ariadne_Szenarienreport_Oktober2021.pdf

Experience from using HBEFA emission database for passenger cars

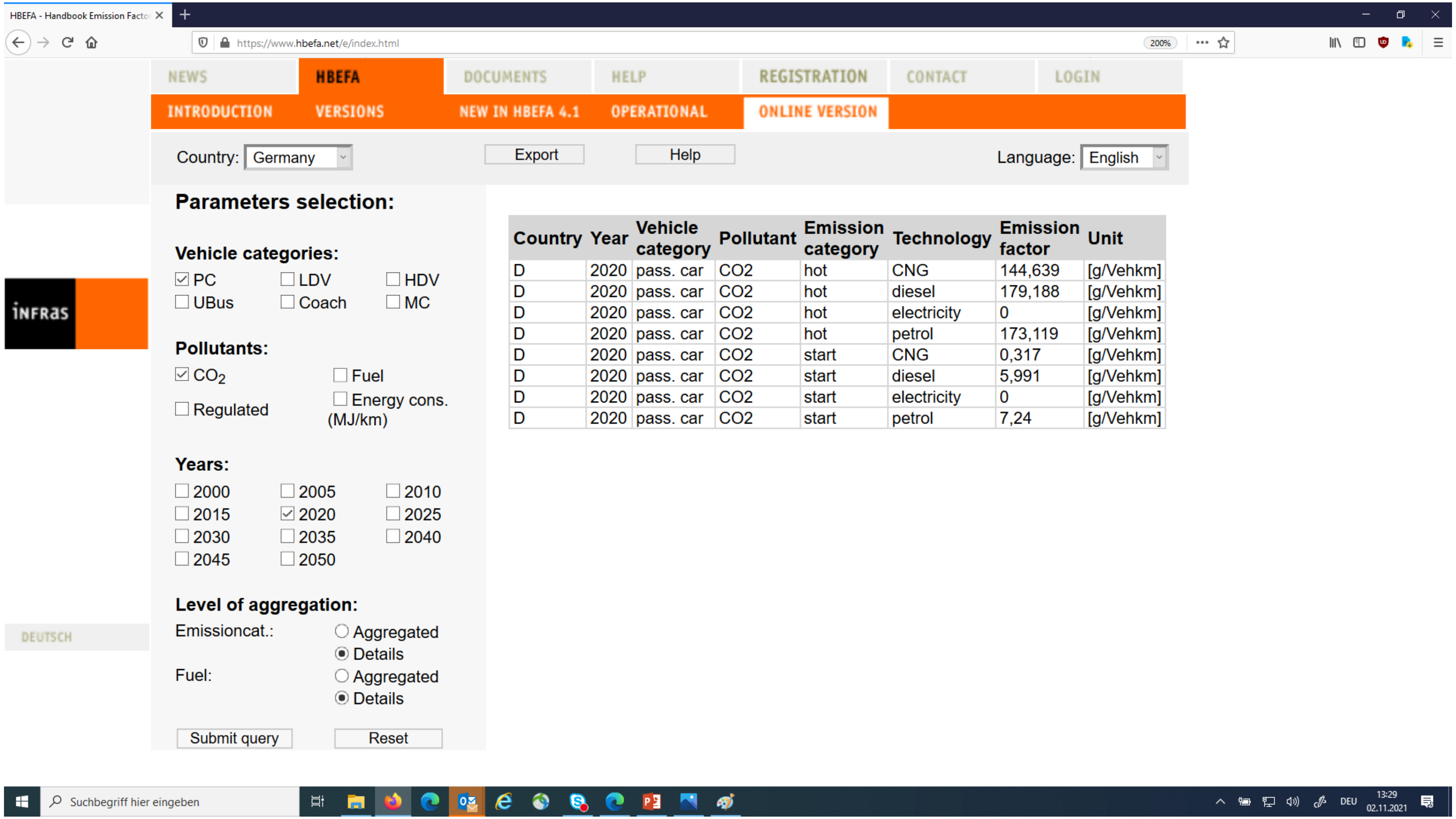
What are emission factors and what are they for?

- Emission factors mainly relate to concentrations in exhaust streams for regulated pollutants (NOx, PM, CO, HC)
- CO_2 is not considered an air pollutant, but a strong and long lasting climate gas
- For vehicles, emission factors are the concentration of a gas in the exhaust stream per unit:
  - Vehicle kilometer
  - Passenger / Tonne kilometer
- Furthermore important are:
  - direct emissions (tailpipe)
  - indirect emissions (upstream, life-cycle emissions)
  - hot emissions (hot driving emissions)
  - cold-start emissions (additional emissions until engine is warm)



Seum et al. (2020) Extended emission factors for future automotive propulsion in Germany considering fleet composition, new technologies and emissions from energy supplies. In: Atmospheric Environment 233 (2020) 117568

HBEFA online allows for an easy access to general emission factors for passenger cars, vans, lorries and busses

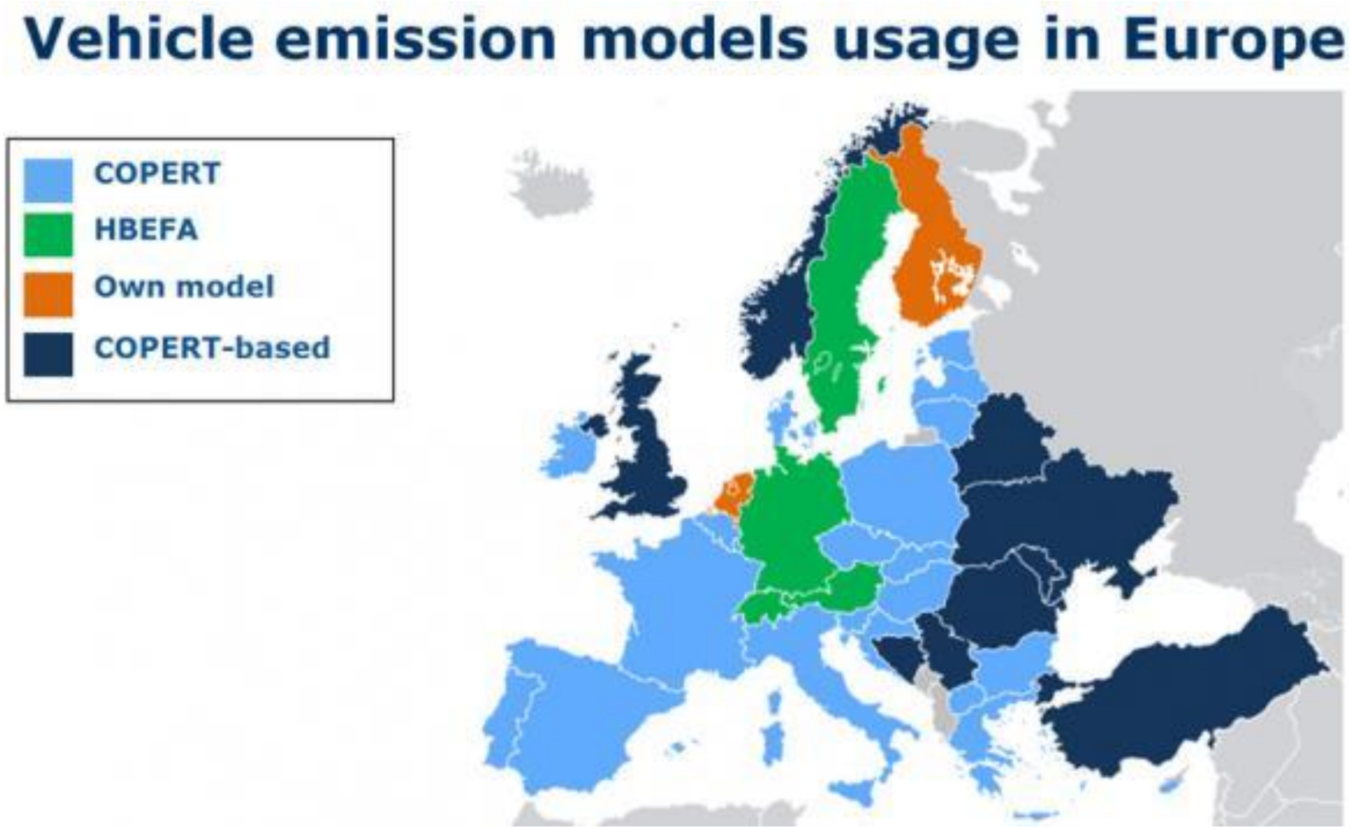


Country	Year	Vehicle category	Pollutant	Emission category	Technology	Emission factor	Unit
D	2020	pass. car	CO2	hot	CNG	144,639	[g/Vehkm]
D	2020	pass. car	CO2	hot	diesel	179,188	[g/Vehkm]
D	2020	pass. car	CO2	hot	electricity	0	[g/Vehkm]
D	2020	pass. car	CO2	hot	petrol	173,119	[g/Vehkm]
D	2020	pass. car	CO2	start	CNG	0,317	[g/Vehkm]
D	2020	pass. car	CO2	start	diesel	5,991	[g/Vehkm]
D	2020	pass. car	CO2	start	electricity	0	[g/Vehkm]
D	2020	pass. car	CO2	start	petrol	7,24	[g/Vehkm]

Inventory Models#3
HBEFA – Handbook of Emission Factors

- COPERT and HBEFA are quite similar in features
- HBEFA allows easier access to data
- Norway and France and EC JRC now also support the use of HBEFA
- Both providing "real-world" emission factors
- For some nations uncertainties in fleet composition

=> Notice: COPERT and HBEFA stem from the same original data harmonization (ERMES European Research on Mobile Emission Sources)



Extracting data for customized passenger car fleets

- HBEFA provides data that allow customizing to your fleet
- Important features are:
  - ➢ three road types (urban, sub-urban and highway)
  - ➢ Technological subsegments (fuel, EURO class)
  - ➢ Bio-fuel share considered or not (CO2)
  - ➢ Energy consumed fossil and electricity
  - ➢ Cold-start emissions
  - ➢ and many more (traffic situation, gradient etc.)
- Before compiling data, one need to decide what features are relevant and how to use them, e.g.:
  - ➢ do I need road-type differentiation?
  - ➢ will I modify bio-fuel content?
  - ➢ will I modify fleet composition?
- **Percent of Subsegment is key for customization!**

Weighted average

VehCat	Year	Compone	RoadCa	Subsegment	%OfSub	EFA	EFA_ag
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin ECE-15'04	6,53E-05	201,7747	172,1947
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin conv other concepts	7,44E-05	201,7747	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Ucat	9,61E-05	201,7747	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin PreEuro 3WCat 1987-9	0,000981	192,9457	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-1	0,007423	192,7969	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-2	0,00969	195,9836	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-3	0,024298	192,1157	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-4	0,163966	181,7266	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-5	0,114961	166,1717	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6ab	0,124399	163,969	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6c	0,021374	163,5191	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6d	0,007574	156,8532	
PKW	2020	CO2(total)	nicht-diffe	PKW Benzin Euro-6d-temp	0,037838	160,554	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-1	0,001546	194,0785	178,3476
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-2	0,004133	187,2148	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-3	0,018826	178,1493	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-3 (DPF)	0,000691	179,9308	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-4	0,01656	183,7499	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-4 (DPF)	0,056089	183,7499	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-5	0,088084	172,9136	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6c	0,023163	181,3822	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6ab	0,152949	177,6226	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6d-temp	0,037963	178,7035	
PKW	2020	CO2(total)	nicht-diffe	PKW Diesel Euro-6d	0,00716	176,4435	
PKW	2020	CO2(total)	nicht-diffe	PKW diesel Euro-5 EA189 nach Soft	0,055676	179,5795	

Example of an extract from HBEFA, ready to be customized

Original Fleet composition in HBEFA

Pulled EFA per propulsioin type

Calculated segment EFA

DLR_Name	VehCat	Year	Component	RoadCat	Technology	Fhrl_Ant_%	EFA	Summe Pkw
G	PKW	2020	CO2(total)	nicht-differenzie	B (4T)	51,2741%	172,19	173,71
D	PKW	2020	CO2(total)	nicht-differenzie	D	46,2838%	178,35	
CNG_B	PKW	2020	CO2(total)	nicht-differenzie	bifuel CNG/petrol	0,3858%	143,95	
BEV	PKW	2020	CO2(total)	nicht-differenzie	electricity	0,3288%	-	
G-PHEV	PKW	2020	CO2(total)	nicht-differenzie	Plug-in Hybrid petrol/elektrisch	0,5744%	65,69	
D-PHEV	PKW	2020	CO2(total)	nicht-differenzie	Plug-in Hybrid diesel/elektrisch	0,0142%	79,64	
LPG_B	PKW	2020	CO2(total)	nicht-differenzie	bifuel LPG/B	1,1382%	169,40	

The fleet composition can now be altered according to the demand, e.g. scenarios, locally specific compositions etc.

Notes

- HBEFA is relatively in-expensive and allows easy access to the „machine room“
- Both, HBEFA and COPERT have limitations:
- Electric vehicles:
  - ➢ still based on few data
  - ➢ efficiency gain in the future unknown
  - ➢ largely varying utility factors
  - ➢ climate factors important
  - ➢ charging loss not considered
- Diesel and gasoline vehicles:
  - ➢ development of divergence between nominal and real-world unknown
- Further aspects might be important and require more tweeking:
  - ➢ cold-start emissions
  - ➢ seasonal variations
  - ➢ location specific geographies

Always compare apple with apple

Data in HBEFA are in emissions per vehicle kilometer!

Never be fooled by nominal fuel consumption

Looking for Kyoto reporting emissions or “real” contribution

Assessing the emissions from public transport

For a complete picture, emissions from public transport may be included

- Public transport consist of diesel (bus, rail) and electric (tram, metro, commuter rail) drive vehicles
- Measures that lead to mode shift will also alter the emissions from public transport
- Information on emissions are rare, mostly energy consumed per seat capacity
- Sources may be literature or statistical data from local transit authorities
- Vehicle capacity utilization are very important for calculation, since mostly passenger transport demand comes in passenger-kilometer (pkm)
- Energy consumed per passenger-kilometer can be transferred to CO_2

Example calculation conducted for a national project (Ariadne)

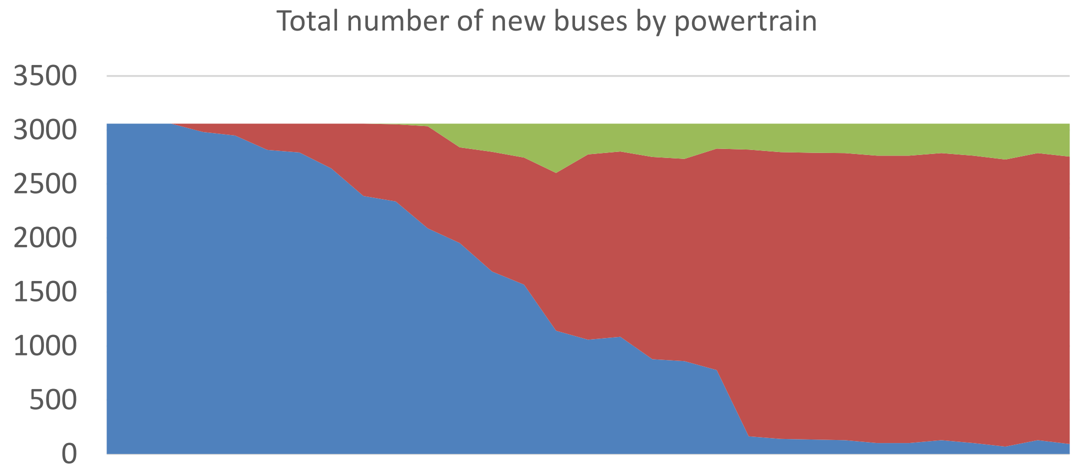
		Energy consumption			
Vehicle type		public bus	tram, metro	light rail	RE/RB/IRE
Base-Year		2010	2010	2009	2009
Reference		TREMOD	TREMOD	DB-AG	DB-AG
Unit			Wh/seat-km	Wh/seat-km	Wh/seat-km
IFEU 2011 (Daten DB AG 2010)			23	26	31
		g diesel/seat-km			g diesel/seat-km
IFEU 2011 (Daten DB AG 2010)		4,7			6,5
vehicle utilization 2010	2010	19,77%	18,60%	29,80%	23,10%
vehicel utilization 2020	2020	20%	20%	35%	24%
reference forecast	2030	20,1%	20,8%	38,1%	24,5%

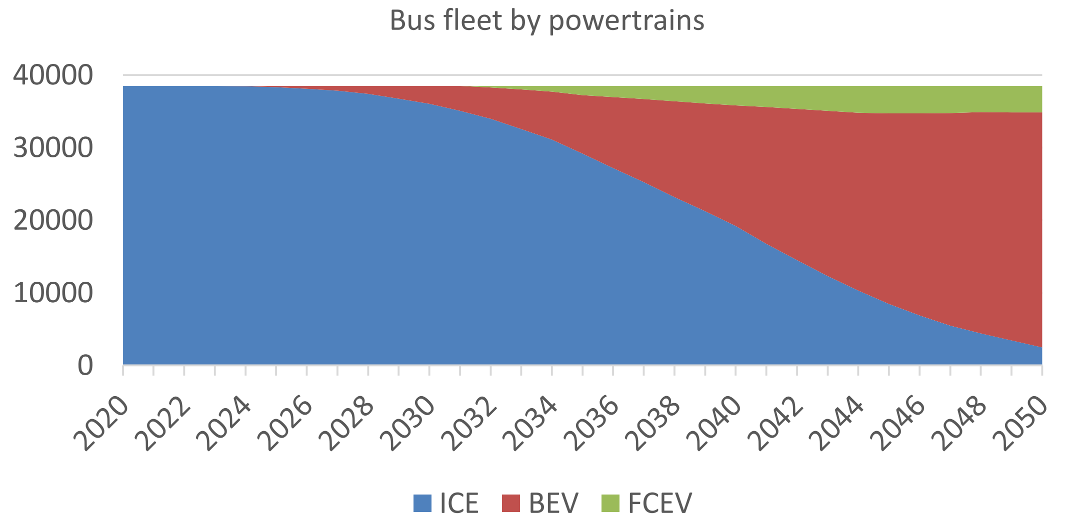
energy consumption per pkm	Base-Year	Reference	Reference
[kWh/pkm] im Jahr	2010	2020	2030
public bus	0,284	0,265	0,252
tram, metro	0,124	0,110	0,101
lght rail	0,087	0,070	0,061
commuter rail elecrtric	0,134	0,122	0,113
commuter rail diesel	0,336	0,306	0,282
commuter rail combined	0,169	0,151	0,138

Simple modelling of the future bus fleet

- What information is needed?
  - Bus fleet size
  - Total number of new buses per year (share that is replaced every year)
  - Average duration the bus stays in the fleet (fixed time of scrapping)
  - Assumptions on market shares of powertrains (e.g. see Clean Vehicles Directive)

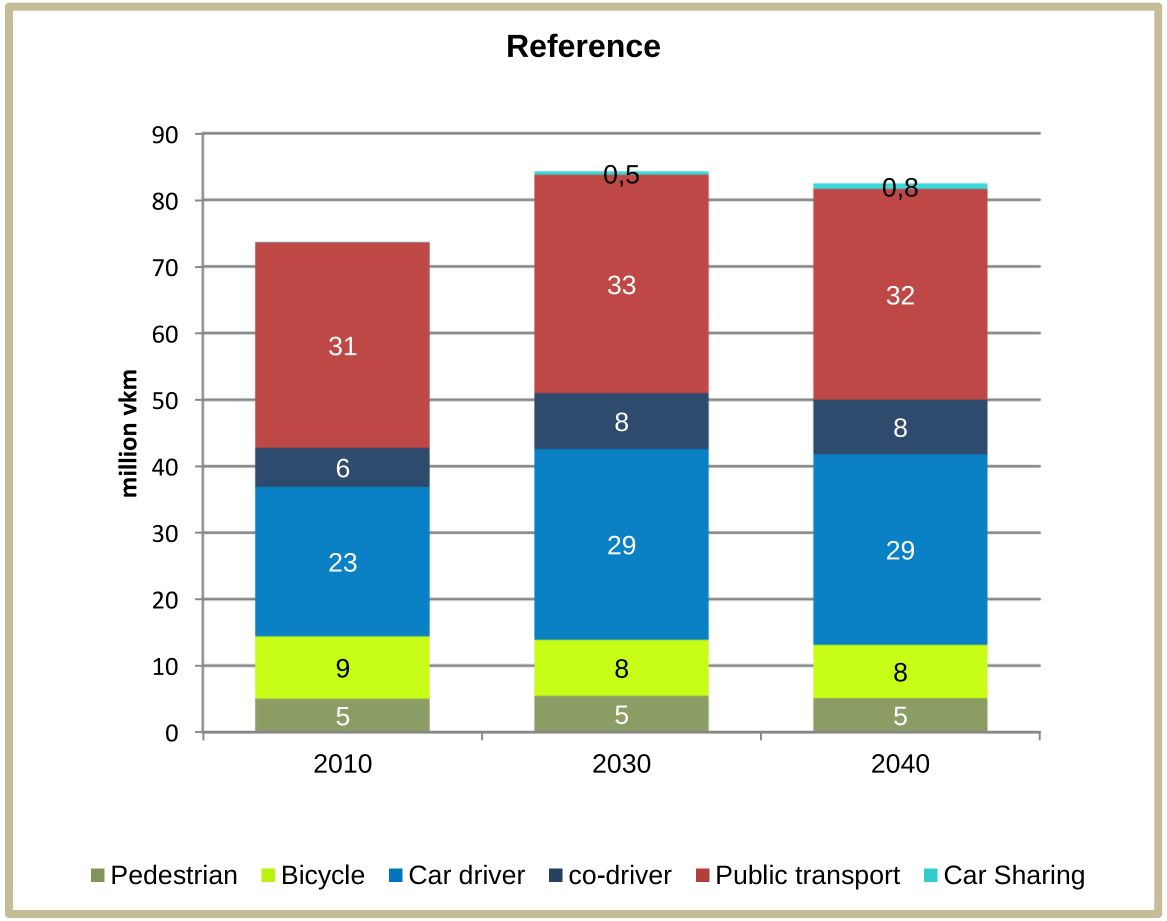
- How to estimate the number of BEV in year t?
  - $Stock_{BEV,t} = Stock_{BEV,t-1} + New_{BEV,t-1} - Scrapped_{BEV,t-1}$
  - With $Scrapped_{BEV,t} = New_{BEV,t-duration}$, a simple diffusion pattern can be modelled.

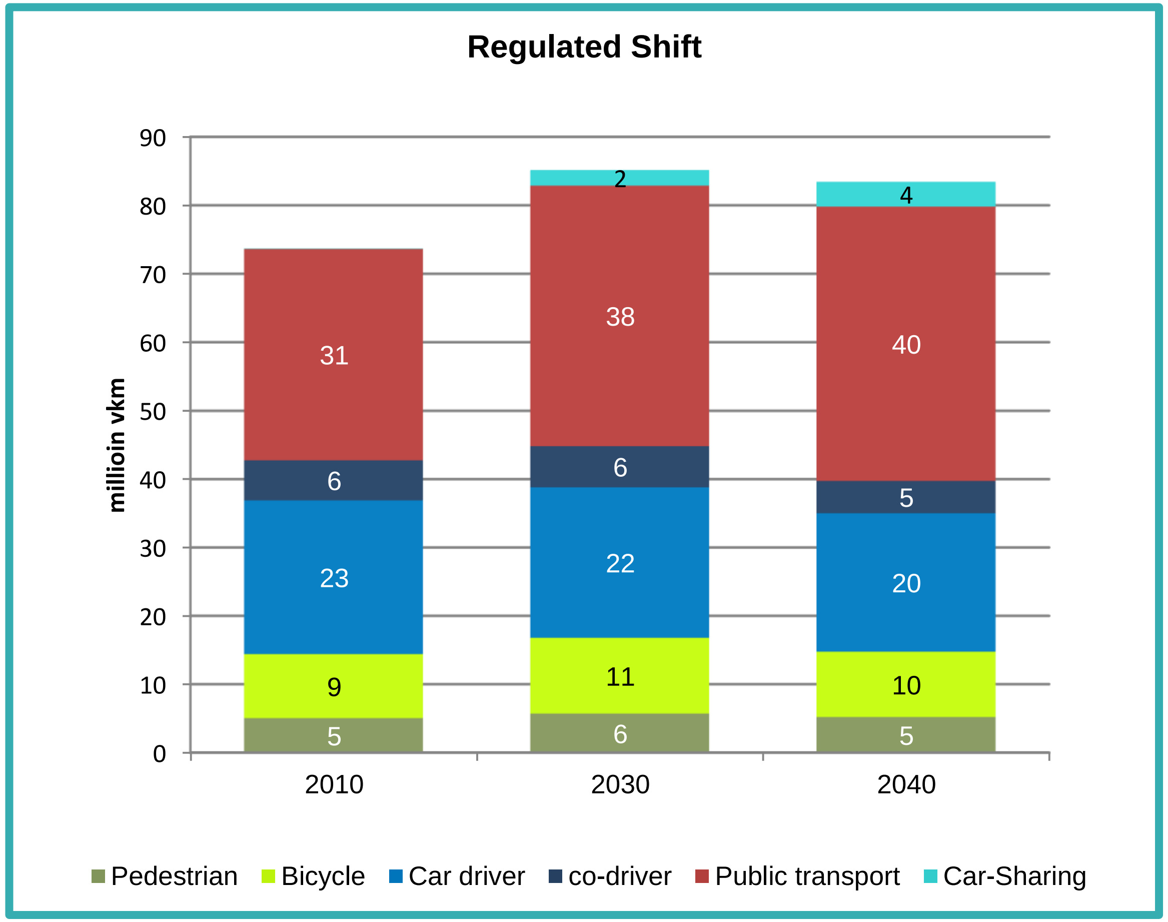




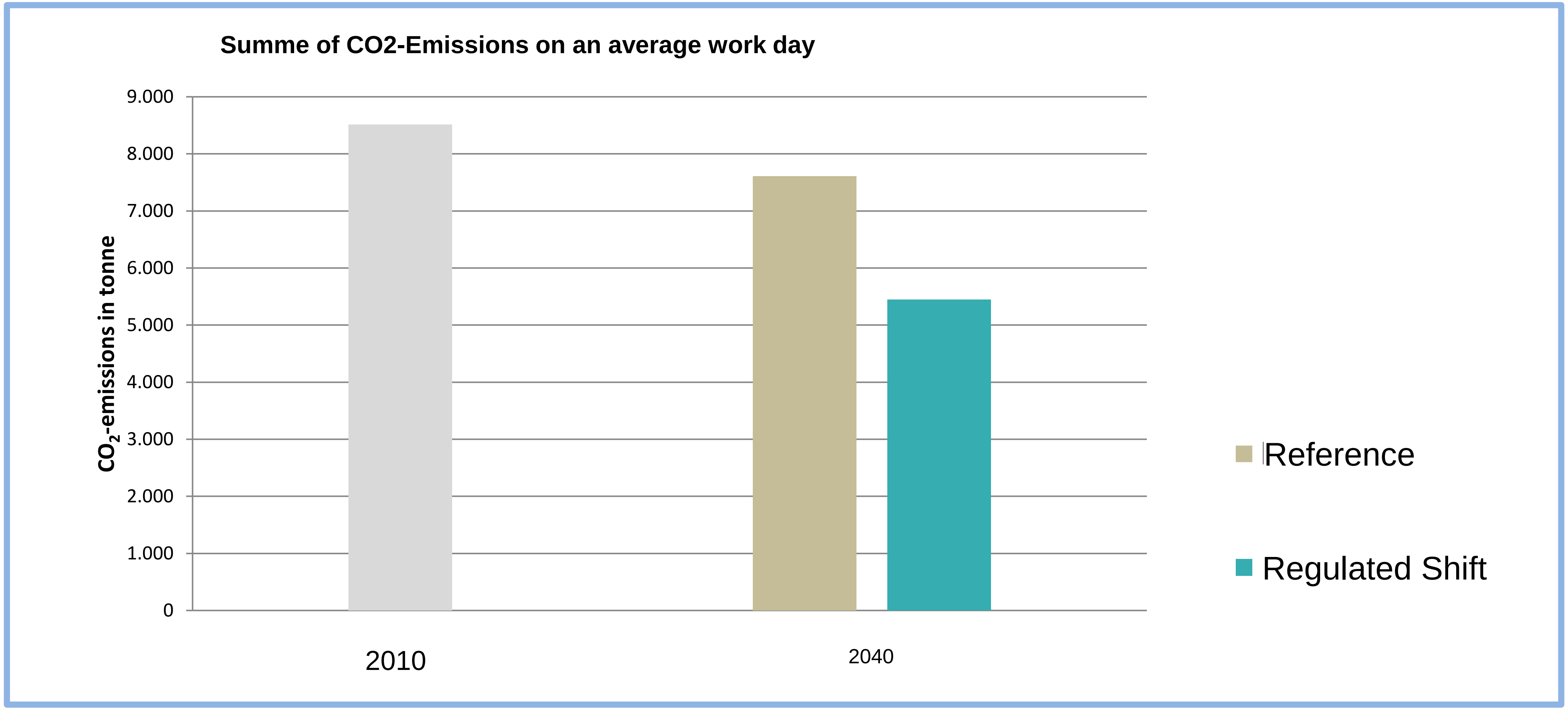
Examples of modelling the implications of policy measures on transport CO2 emissions

Example analysis of a transport scenario for the City of Berlin 2010 – 2030 – 2040





Direct CO2-Emissions are expected to decline; the level depends on the level of policy measures



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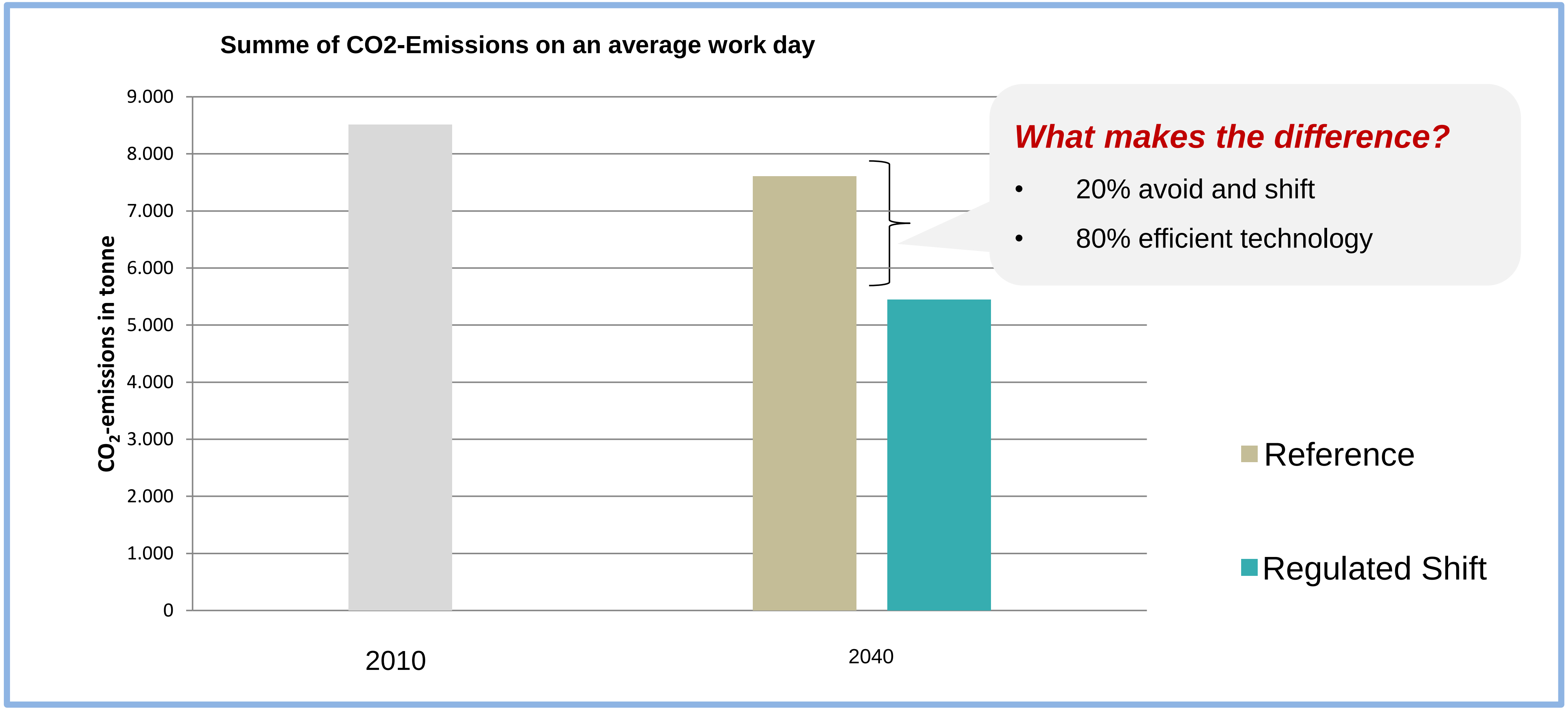

Conclusion

- CO_2 emissions are generated when fossil fuels are burned inside internal combustion engines.
- CO_2 emissions of the transport sector refer to tailpipe emissions (Tank-to-Wheel).
- Modelling CO_2 emissions of the transport sector can be done in much detail but also through good assumptions and simple calculations.

Thank you for your attention! ☺