Fact sheet

THE ENVIRONMENTAL BURDENS
OF PASSENGER CARS: TODAY AND TOMORROW

This fact sheet and the corresponding background report describe the environmental burdens of current and future passenger cars on the basis of life cycle assessment. The assessment includes the entire life cycle of vehicles: manufacturing, operation and end-of-life. It also includes the production chain of the fuel, whether petrol, diesel, gas, electricity or hydrogen (H_2) and the entire fuel chain infrastructure. This life cycle perspective is important because, although battery and fuel cell vehicles do not emit any pollutants through their exhaust, the environmental burdens of producing these vehicles and the electricity and hydrogen that they consume can be substantial.

Vehicle technologies and fuels

Conventional vehicles with combustion motors (ICEV) can be operated using petrol, diesel or gas. Alternatively, vehicles can be powered by electric motors, such as battery or fuel cell electric vehicles (BEV and FCEV, respectively). The "fuel" for these vehicles is electricity that is either stored directly in batteries, or in the form of hydrogen that is converted into electricity using fuel cells as it is needed. Plug-in hybrids have an onboard battery that can be charged from the electricity grid and also a combustion motor. They can operate either in electric or combustion mode. In the future, electricity vehicles may operate using synthetic natural gas (SNG). In this case, electricity is used indirectly to produce hydrogen via electrolysis. This hydrogen is then reacted with CO_2 to produce SNG which can be combusted in standard combustion motors to power vehicles (ICEV-SNG).

The contents of this fact sheet are based on the dissertation of Brian Cox and the life cycle assessment activities at the Paul Scherrer Institute (https://www.psi.ch/ta/) as part of the SCCER Mobility (http://www.sccer-mobility.ch/). Direct contact: Christian Bauer (christian.bauer@psi.ch).

SUMMARY OF FINDINGS:

- When BEV and FCEV are powered by electricity or hydrogen from sources with low CO_2 emissions, they cause substantially lower greenhouse gas emissions than petrol, diesel and gas powered ICEV (figure 1 Greenhouse gas emissions and figure 4).
- This means that the introduction of electric mobility should be accompanied by an increase in renewable electricity generation capacity. Electricity should also be used more efficiently in other sectors.
- Electric vehicles cause essentially zero direct exhaust emissions, and can thus help improve air quality in regions with high transport demand.
- The production of BEV and FCEV causes greater environmental burdens and is more elaborate than the production of ICEV. Increased greenhouse gas emissions from vehicle production can be compensated for by lower operating emissions after roughly 50’000 kilometres of vehicle life, as long as electricity and hydrogen are from low CO_2 sources (figure 3).
- The CO_2 balance of BEV depends strongly on the CO_2 intensity of the electricity used to charge the battery (figure 4). This is also true for FCEV and ICEV that operate using synthetic natural gas produced using the "power-to-gas" process.
- BEV have the highest overall energy efficiency. FCEV and ICEV operated with synthetic natural gas are less efficient, especially due to large energy losses in the fuel production chain.
- With this in mind, BEV are the best option among the low emission vehicles to use renewable electricity most efficiently.

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The life cycle assessment results in figures 1 to 4 represent average mid-sized vehicles. The basic parameters for the vehicles are summarized in table 1.

			lifetime	vehicle mass	fuel consumption (Real operation)		range	efficiency "tank-to-wheel"	emissions-standard for exhaust emissions
			km	kg	l gasoline eq. per 100 km	per 100 km	km	%	
2017	ICEV	petrol	180'000	1357	7,6	7,6 litre	524	21	EURO 6
		diesel		1380	6,9	6,3 litre	656	23	EURO 6
		gas		1434	8,5	5,8 kg	512	19	EURO 6
	battery electric			1595	2,2	19,5 kWh	173	64	
	fuel cell electric			1570	4,0	1,1 kg	468	34	
2040	ICEV	benzin	180'000	1319	5,0	5,0 litre	669	27	EURO 6 –50%
		diesel		1340	4,9	4,5 litre	775	28	EURO 6 –50%
		gas		1383	5,4	3,7 kg	641	26	EURO 6 –50%
	battery electric			1554	1,9	16,6 kWh	439	78	
	fuel cell electric			1462	3,1	0,8 kg	601	46	

Table 1: Base vehicle parameter values in the life cycle assessment

The improvements in 2040 vehicle emissions and energy consumption visible in the following figures 1 to 4 are mostly due to expected technological improvements: motor efficiency increases, vehicle weight reductions and exhaust emissions reductions.

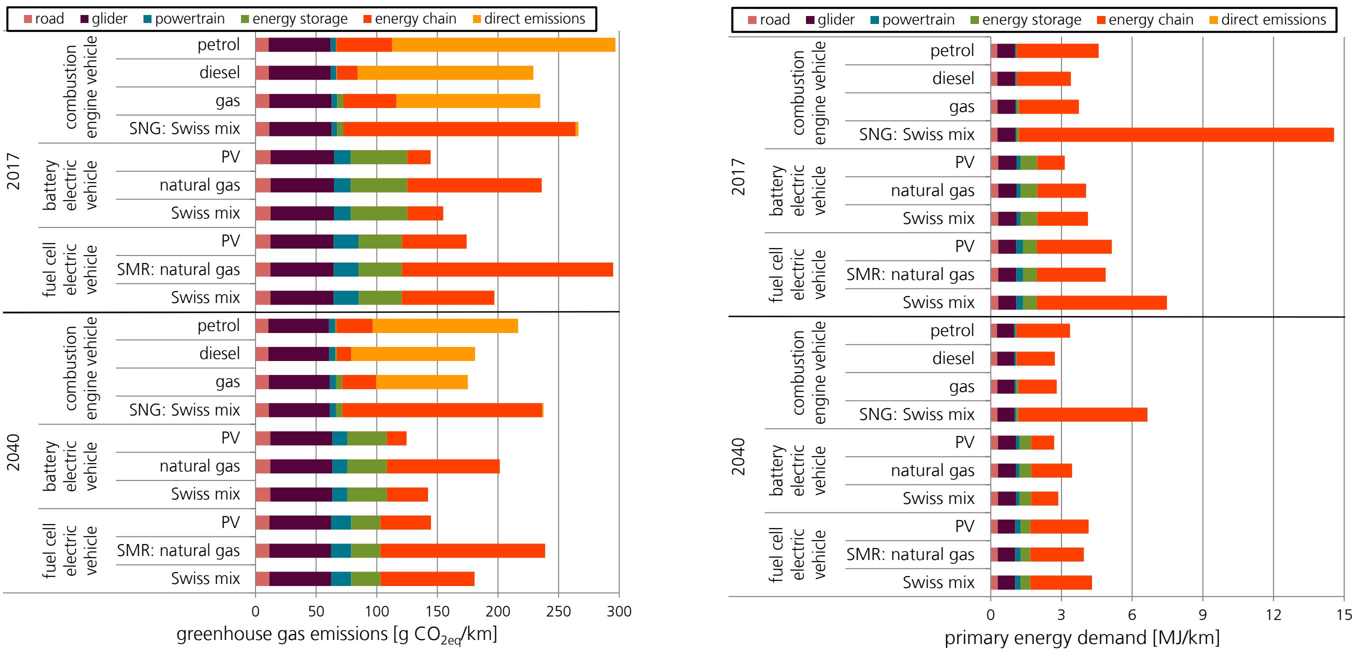

Figure 1: Greenhouse gas emissions (left) and primary energy demand (right) from passenger vehicles in 2017 and in 2040 per vehicle kilometre. "PV": photovoltaic; "SNG": Synthetic natural gas, here produced via electrolysis using the Swiss electricity mix and CO_2 captured from ambient air; hydrogen for fuel cell vehicles is produced either via steam methane reforming ("SMR") or electrolysis (Swiss electricity mix or PV electricity); "Gas" is a mix of 90% fossil natural gas and 10% biogas. The different coloured bars show the source of the emissions: production, maintenance, end-of-life of individual vehicle components and the road, the fuel production chain and the direct emissions of the vehicles.

Figure 2 shows that a substantial portion of the pollution due to electric vehicles is caused by the production of the battery. These emissions are, however, generally released in sparsely populated areas where few people can be affected, for example, in mines where raw metals are produced. The resulting health impacts are estimated to be much lower compared to emissions that occur in densely populated areas with high transport demand. Nonetheless, some of these emissions are shifted to densely populated industrial centers in Asia where batteries are produced and many people are affected by it.

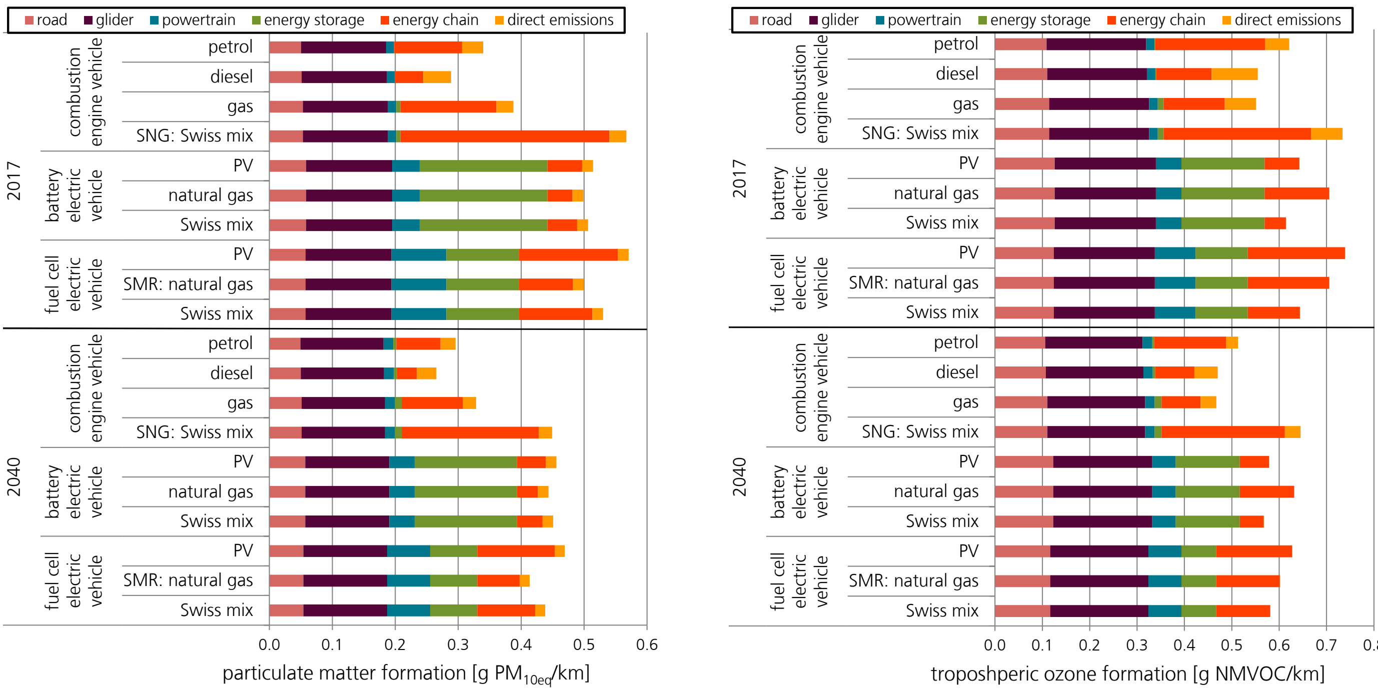

Figure 2: particulate pollution (left) and emission of air pollutants that cause summer smog (right) from passenger vehicles in 2017 and in 2040 per vehicle kilometre. "PV": photovoltaic; "SNG": Synthetic natural gas, here produced via electrolysis using the Swiss electricity mix and CO_2 captured from ambient air; hydrogen for fuel cell vehicles is produced either via steam methane reforming ("SMR") or electrolysis (Swiss electricity mix or PV electricity); "gas" is a mix of 90% fossil natural gas and 10% biogas. The different coloured bars show the source of the emissions: production, maintenance, end-of-life of individual vehicle components and the road, the fuel production chain and the direct emissions of the vehicles.

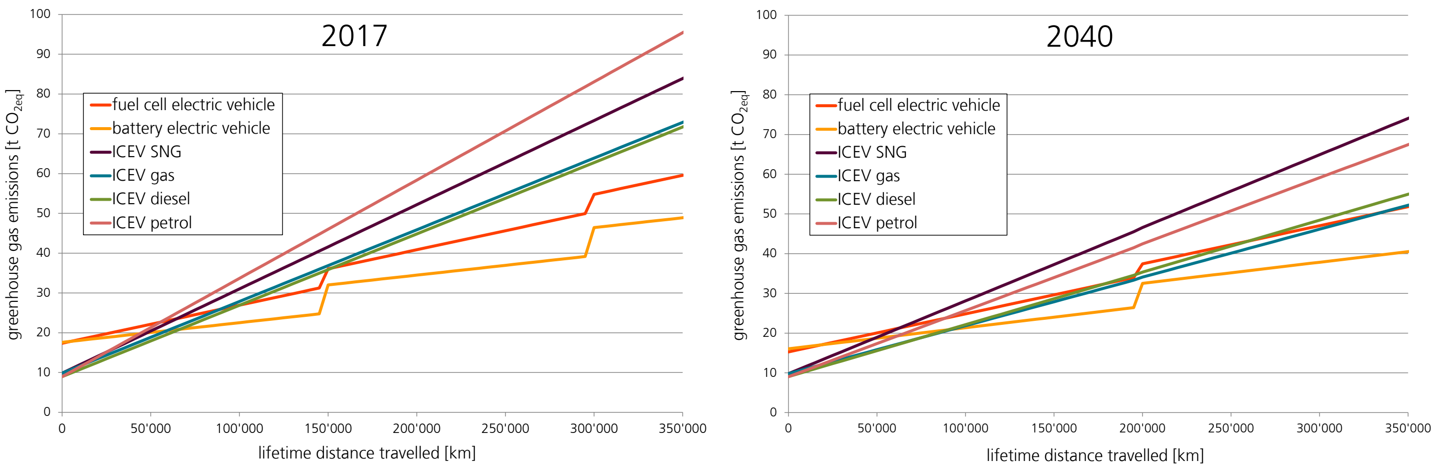

Figure 3: Greenhouse gas emissions during the entire life cycle of different vehicle powertrain types in 2017 (left) and in 2040 (right). "ICEV": vehicle with combustion motor; "SNG": Synthetic natural gas, here produced via electrolysis using the Swiss electricity mix and CO_2 captured from ambient air. The Swiss electricity mix is assumed here for both the charging of batteries for battery electric vehicles and for the production of hydrogen for use in fuel cell vehicles. "Gas" is a mix of 90% fossil natural gas and 10% biogas. Batteries and fuel cells are assumed to be replaced after 150'000 km (2017) and 200'000 km (2040).

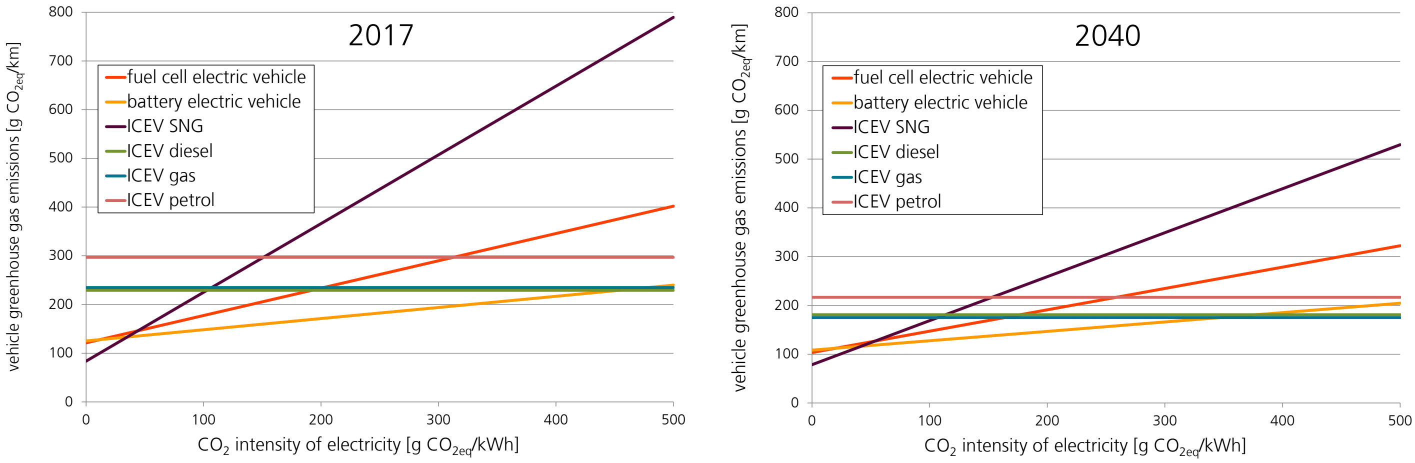

Figure 4: Greenhouse gas emission dependency on CO_2 intensity of the electricity used to charge batteries for battery electric vehicles, to produce hydrogen for fuel cell vehicles, or to produce synthetic natural gas. "ICEV": vehicle with combustion motor; "SNG": Synthetic natural gas, here produced via electrolysis and CO_2 captured from ambient air. "Gas" is a mix of 90% fossil natural gas and 10% biogas. Battery electric vehicles show the best advantages compared to fossil fueled vehicles because of their efficient use of electricity. For electricity with extremely low CO_2 intensity, SNG vehicles have the best performance because the production of batteries and fuel cells can be avoided. The lines for BEV, FCEV, and ICEV-SNG are less steep for 2040 than for 2017 because vehicle efficiency is expected to increase and vehicles will require less energy per kilometre driven in the future. For reference: hydro and wind electricity in Switzerland have CO_2 intensities of roughly 10–30 g CO_{2eq}/kWh; photovoltaic systems produce roughly 70–100 g CO_{2eq}/kWh; natural gas power plants would reach levels around 400–500 g CO_{2eq}/kWh and the current Swiss electricity mix has a CO_2 intensity of slightly over 100 g CO_{2eq}/kWh.

THE ENVIRONMENTAL IMPACTS OF BATTERY PRODUCTION

Lithiumion batteries are the current standard for battery electric vehicles, the production of which results in substantial environmental burdens. Thus, vehicles with larger batteries, and correspondingly larger ranges, tend to have larger environmental burdens. A current battery system weighing 350 kg has a storage capacity of roughly 40 kWh, though thanks to improving energy density of batteries, a battery system of the same weight may store roughly 90 kWh in the year 2040. The lifetimes for current and 2040 batteries are assumed to be 150'000 km and 200'000 km, respectively. The most important factor for the environmental burdens of battery production is the energy consumed during the production of the battery cells. The two main determinates are how much electricity this process consumes and how that electricity is generated. Better life cycle assessment results are found for vehicles with "clean" battery production, efficient recycling processes, and "second-lives" for the batteries, for example as storage capacity for photovoltaic systems in buildings. However, such "second-lives" are not considered here.

VALIDITY OF LIFE CYCLE ASSESSMENT

Several assumptions and key parameters have significant impact on the life cycle assessment results of passenger cars. These include fuel consumption, exhaust emissions from combustion motors, lifetimes of vehicles and key components such as batteries. The results in this fact sheet are valid for the input assumptions listed in table 1. The background report contains realistic ranges for all input values and shows their impact on results. For example: What changes if diesel vehicles fail to meet emission requirements and produce significantly more nitrogen oxides than allowed? Or, how would results change if batteries were produced with an entirely renewables-based electricity system? The background report documents all input parameters and data sources. Furthermore, additional results, for example for plug-in hybrid vehicles are included.

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