Environmental impacts of future urban deployment of electric vehicles: Assessment framework and case study of Copenhagen for 2016-2030

Electronic Supporting Information (ESI)

Florence A. Bohnes [a]*, Jay S. Gregg [b] and Alexis Laurent [a]

[a]: Division for Quantitative Sustainability Assessment (QSA), Department of Management Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark.
[b]: Division for System Analysis (SYS), Department of Management Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark.

* To whom correspondence should be addressed; e-mail flbo@dtu.dk. Postal address: DTU Management Engineering, Bygningstorvet, Building 116B, Room 104A, 2800 Kgs. Lyngby (DENMARK).

Table of Contents

Supporting Figures

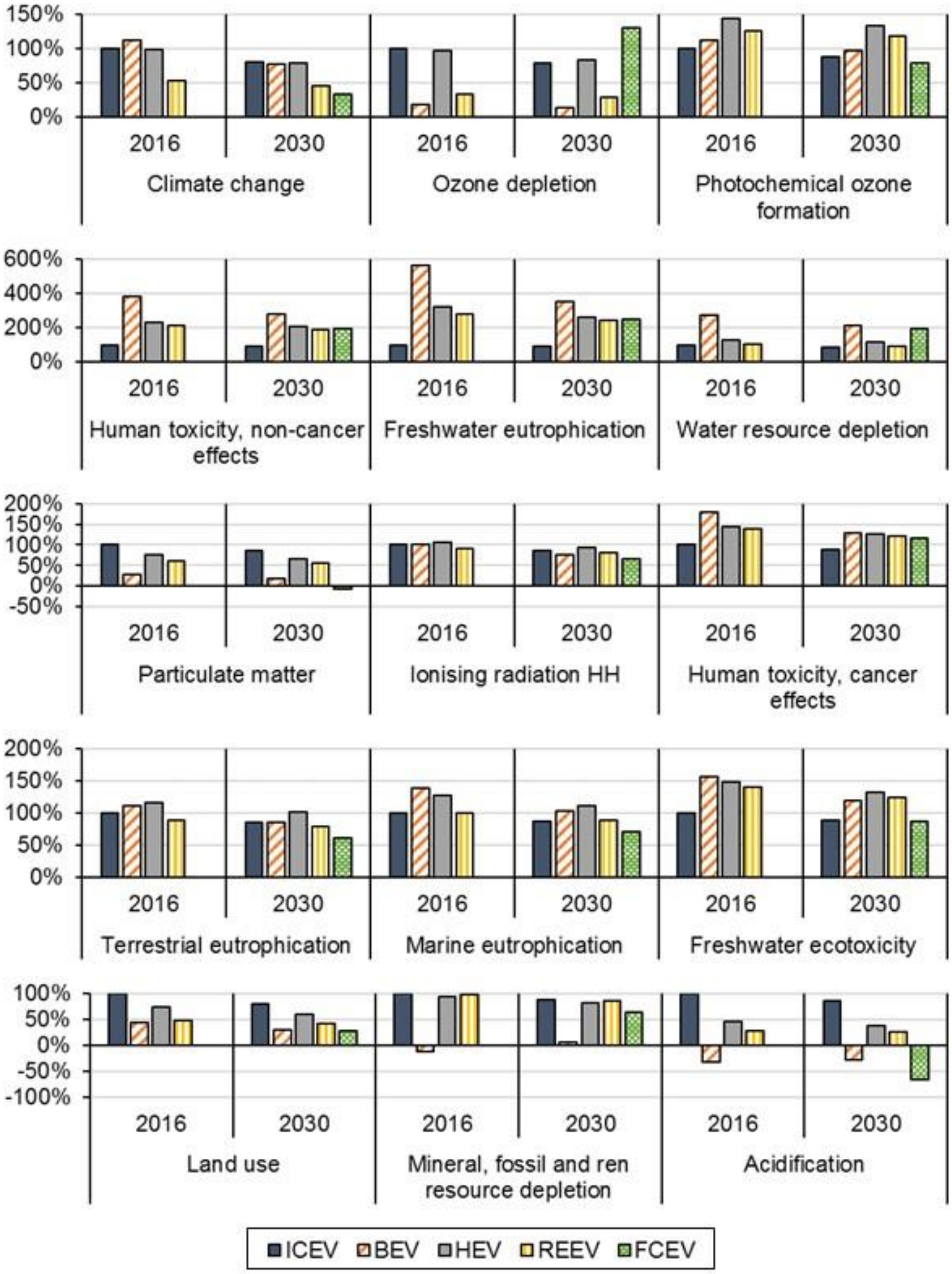

Figure S1: Comparison of all vehicles in 2016 and 2030 in 15 impact categories based on transport of 1 km in a passenger car. Results are indexed on the impact scores obtained for ICE vehicles in 2016. The fuel cell vehicles (FCEV) are not in place in 2016, hence not apparent on the figures for that year.

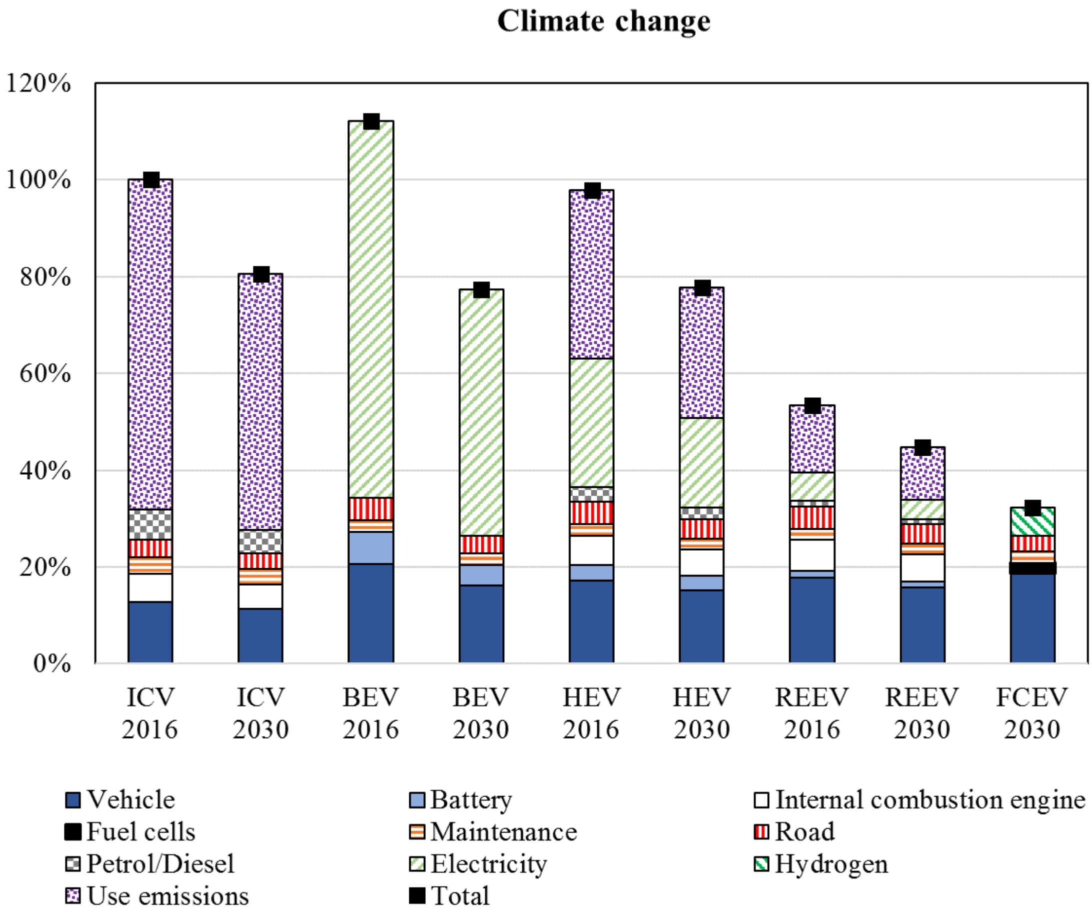

Figure S2: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories climate change. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016. *The climate change impacts of FCEV seems especially low compared to the other vehicles. The vehicle part of the FCEV is similar to the other vehicles. The noticeable difference in the final score is actually due to the use phase, i.e. emissions during the use and the emissions from the fuel production. The vehicle modeled in our study consumes 9.0E-3 kg H2/km (see calculations in Supporting Methods), which is slightly lower but still comparable to the H2 consumption used in Bauer et al.*[1] *(10.1E-3 kg H2/km) and Simons and Bauer*[2] *(13E-3 kg H2/km). The difference thus only comes from the H2 production, and this was also a conclusion reached by Simons and Bauer*[2]*. When looking at Figure 3 in the manuscript, it can be observed that, with the less impactful H2 production mean, Bauer et al.*[1] *found similar final scores for FCEV in climate change than in our study.*

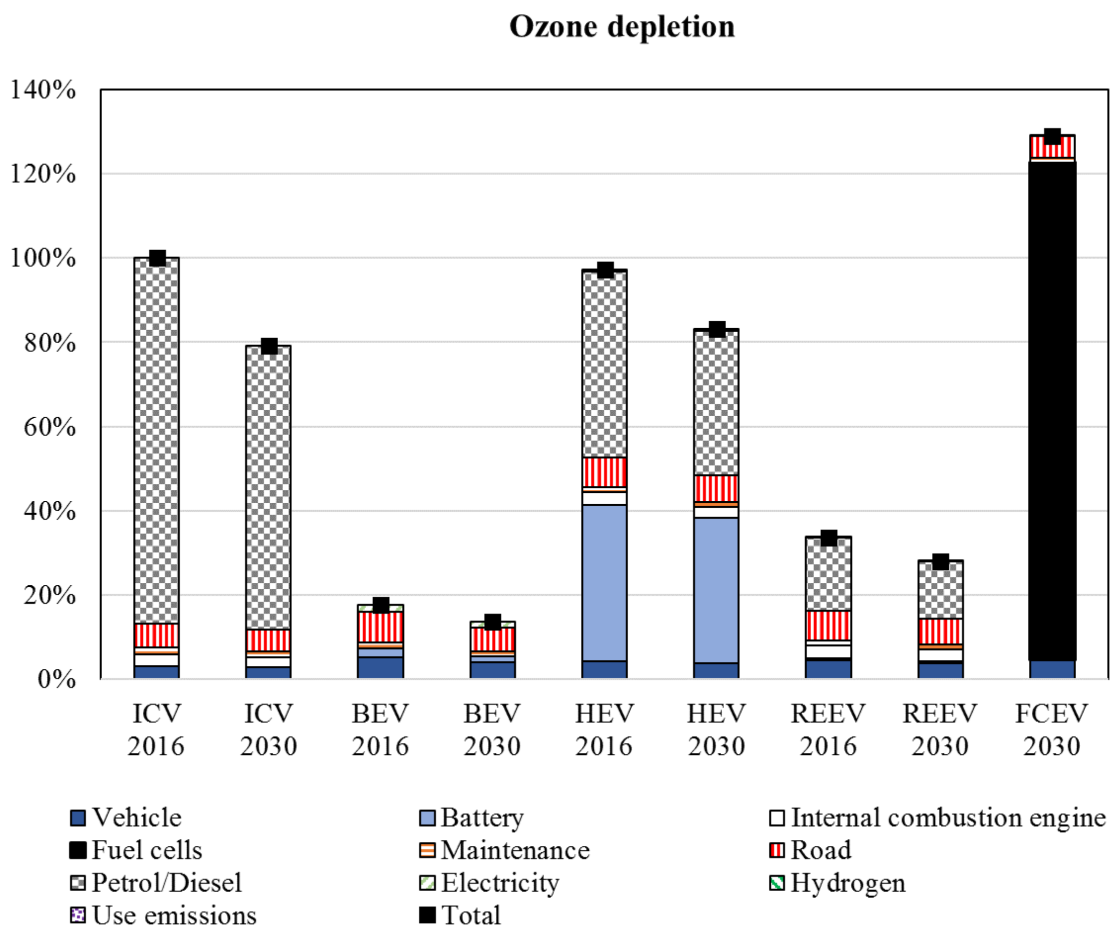

Figure S3: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories ozone depletion. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016. *It can noticed that the impacts from the battery for the HEV are much bigger than for the other vehicles because pure HEV are not equipped with the same Li-ion battery, but with NiMH batteries.*

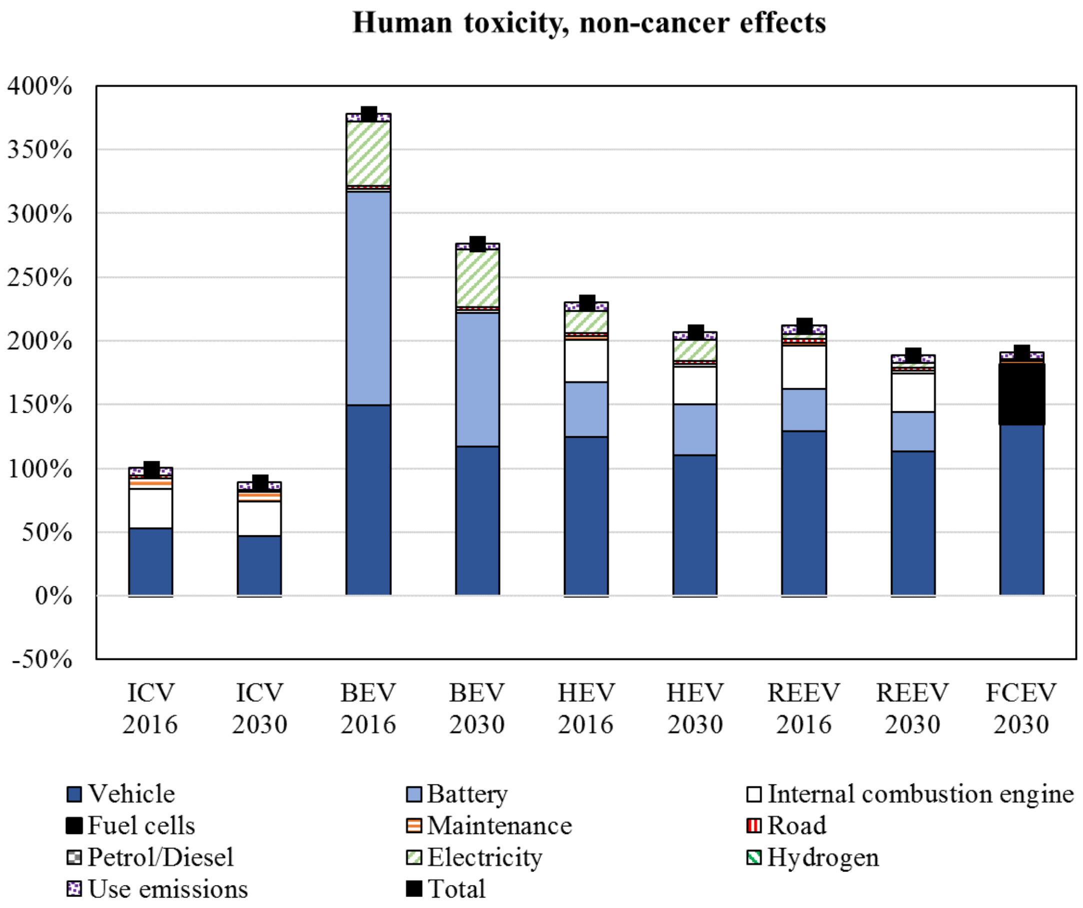

Figure S4: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories human toxicity (non-cancer effects). Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

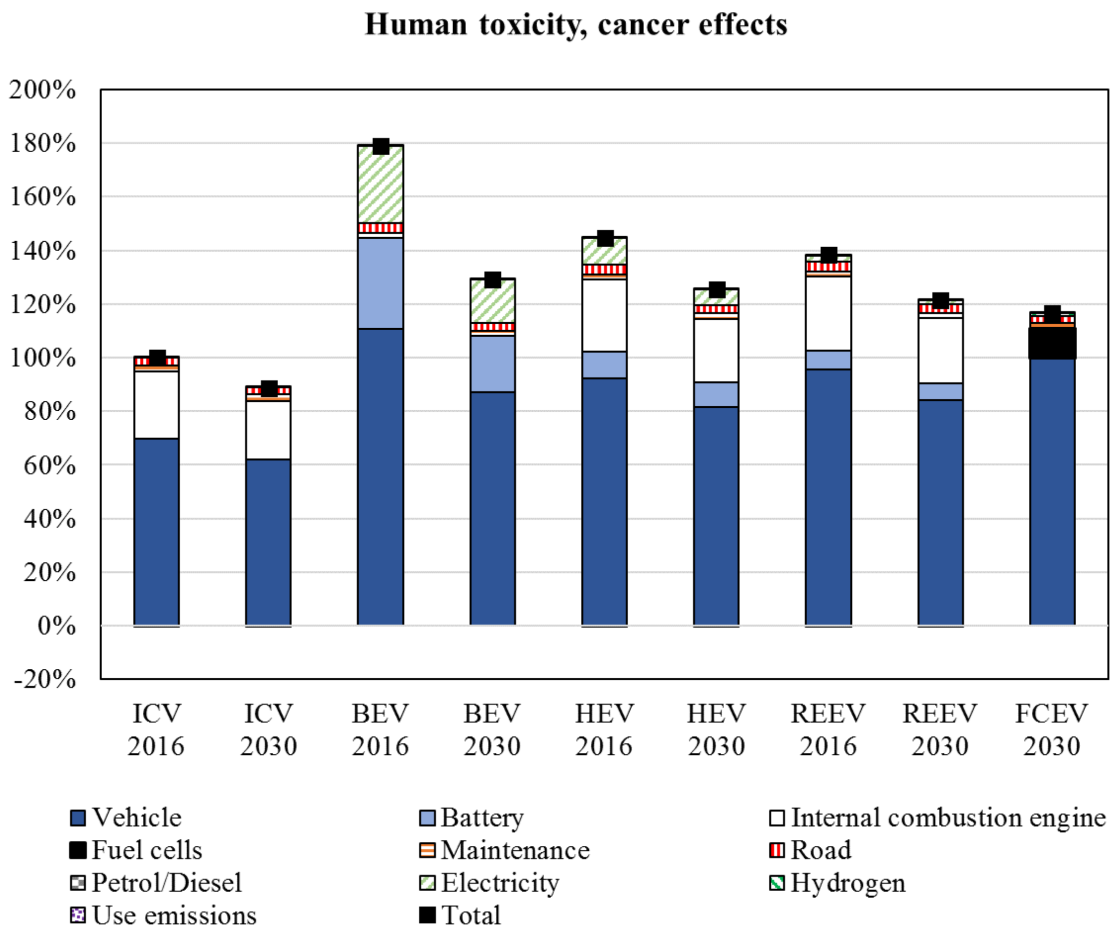

Figure S5: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories human toxicity (cancer effects). Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

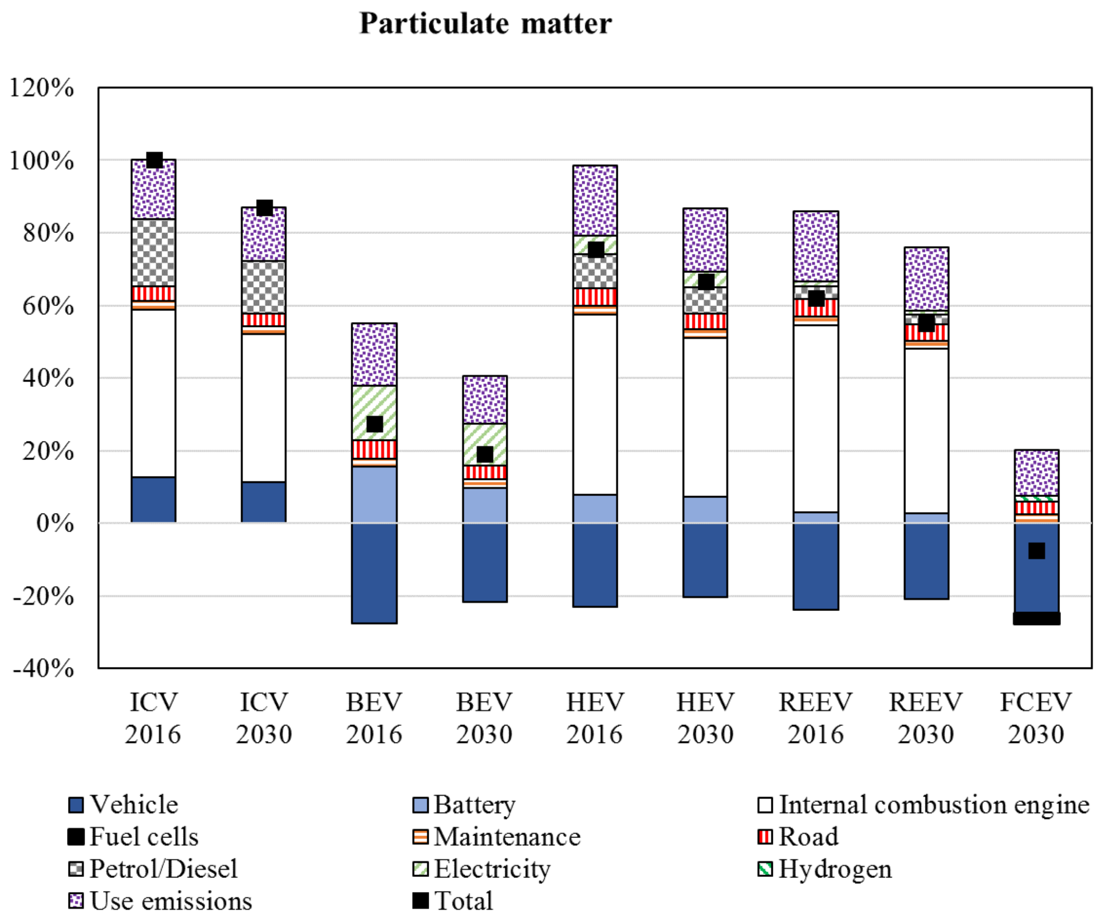

Figure S6: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories particulate matter. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

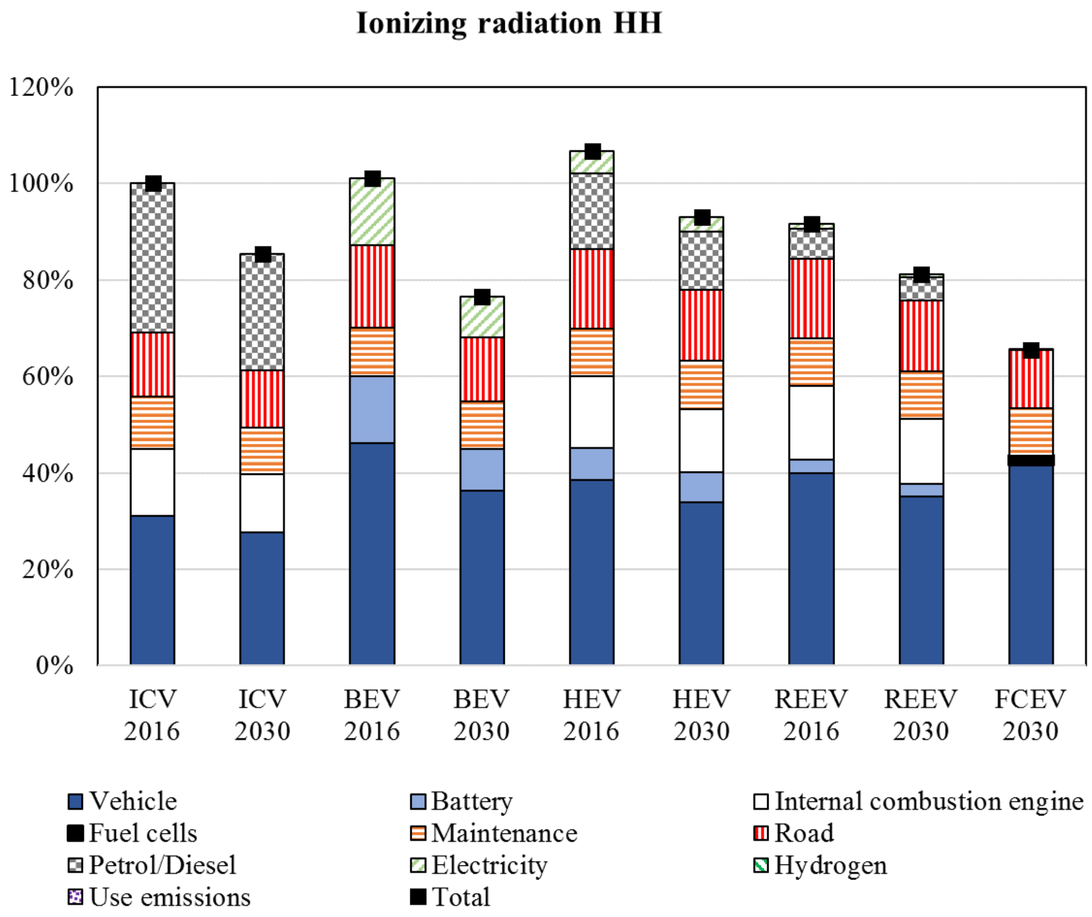

Figure S7: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories ionizing radiation HH. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

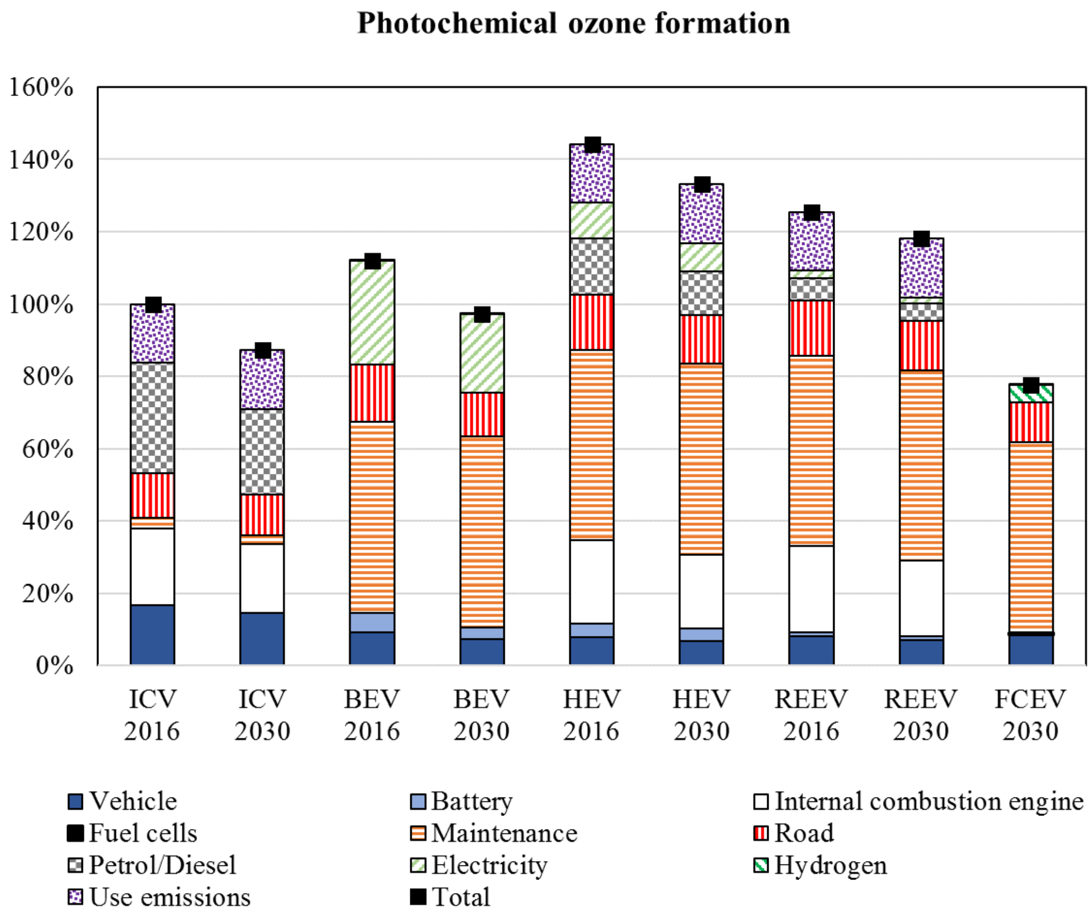

Figure S8: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories photochemical ozone formation. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016. *It should be noticed here that there might be an overestimation of the impacts of maintenance for electric/partly electric vehicles because of an inventory mistake in Ecoinvent (use of 38 kg of Ethylene in both maintenance processes but emissions of corresponding 38 kg Ethene only in the case of electric vehicles)*

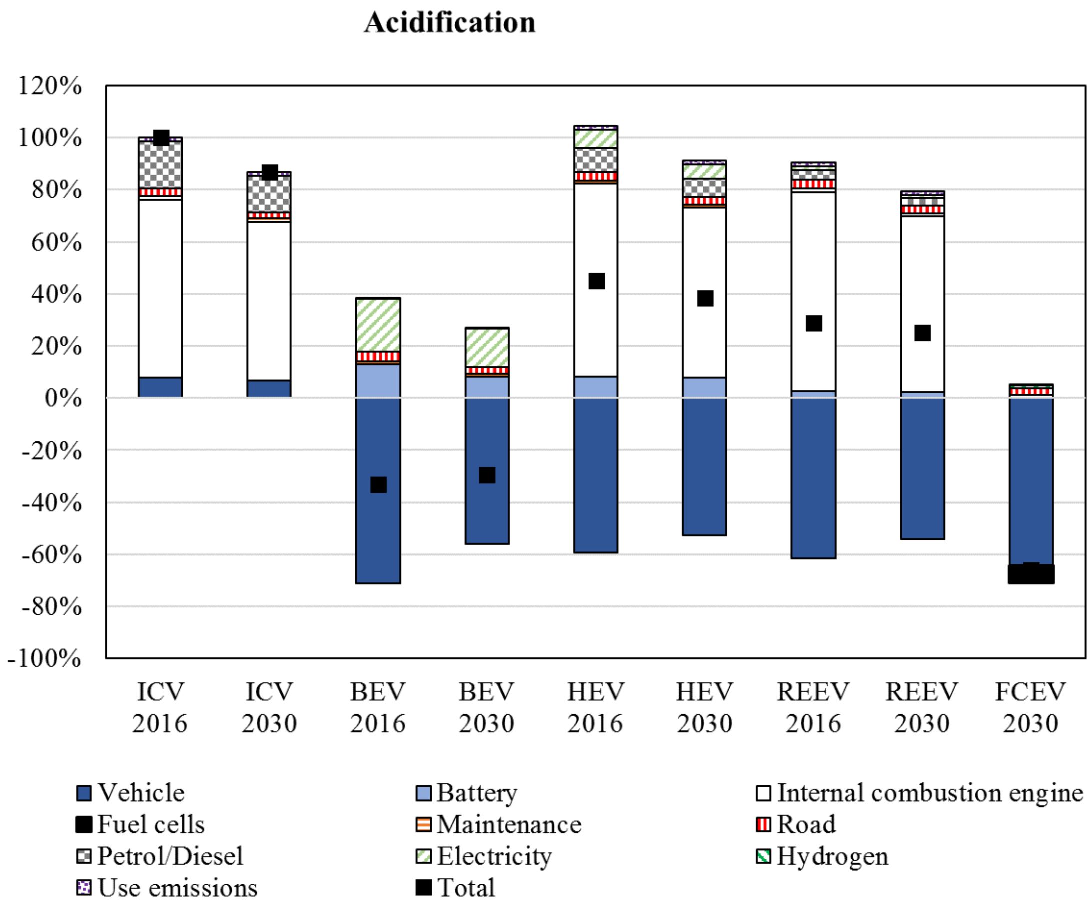

Figure S9: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories acidification. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

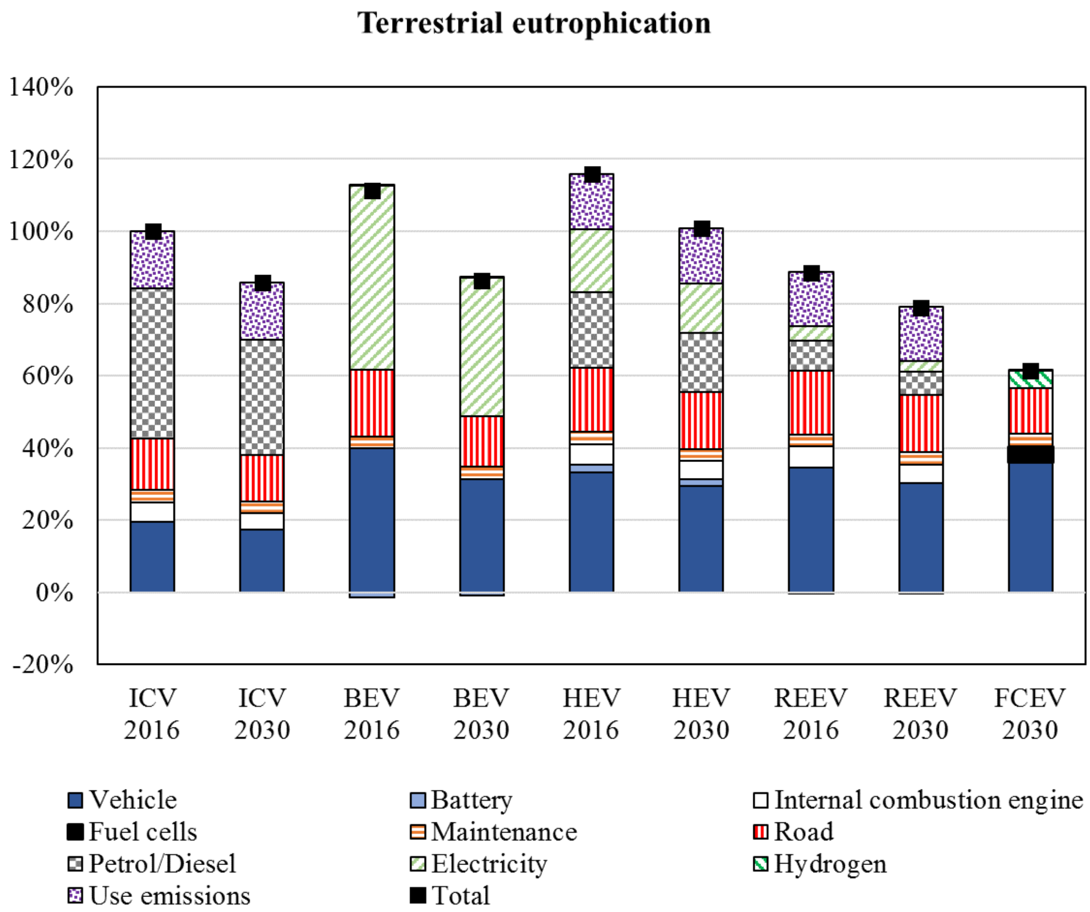

Figure S10: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories terrestrial eutrophication. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

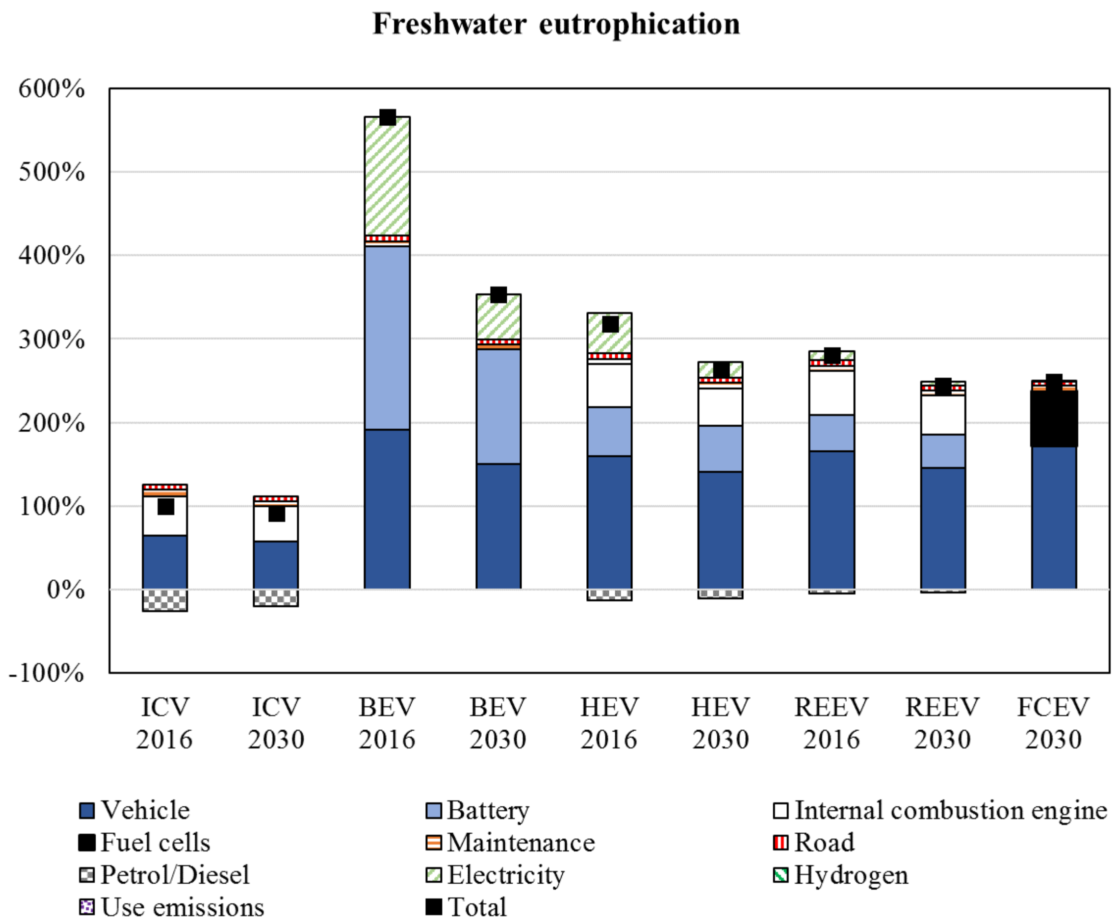

Figure S11: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories freshwater eutrophication. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

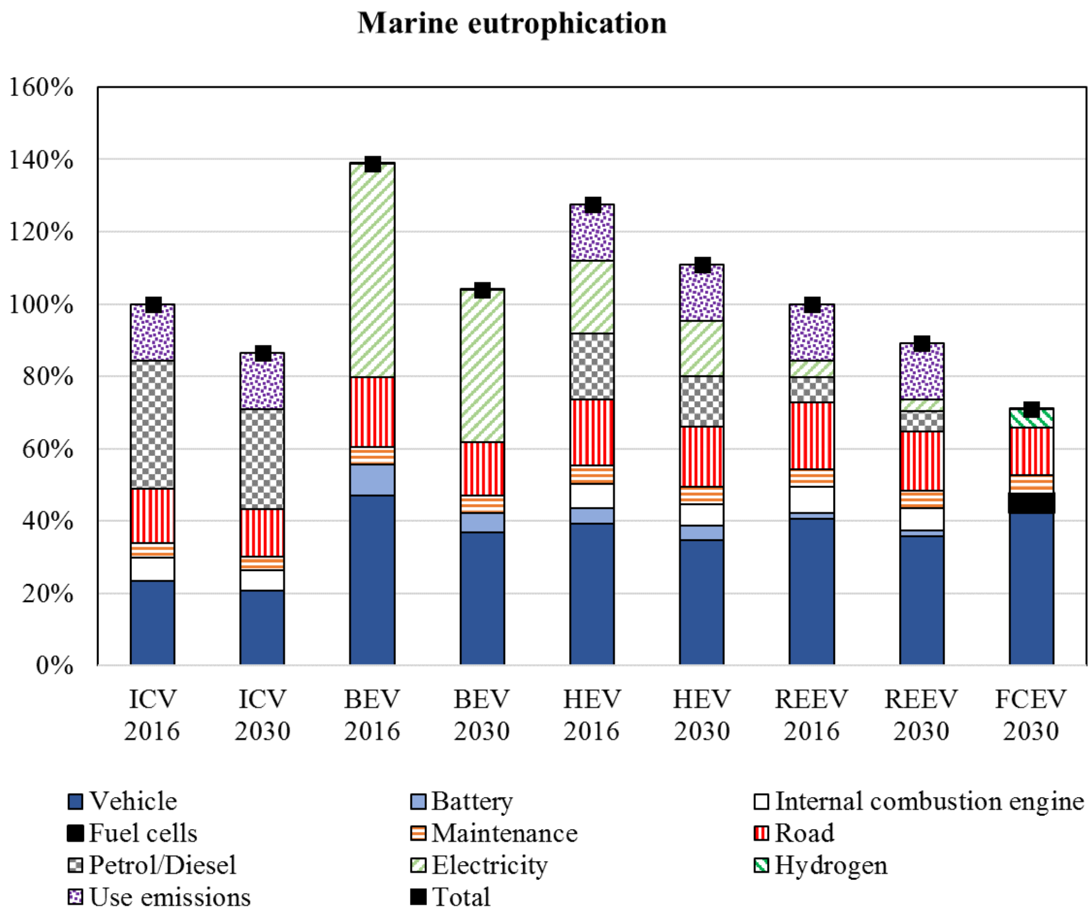

Figure S12: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories marine eutrophication. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

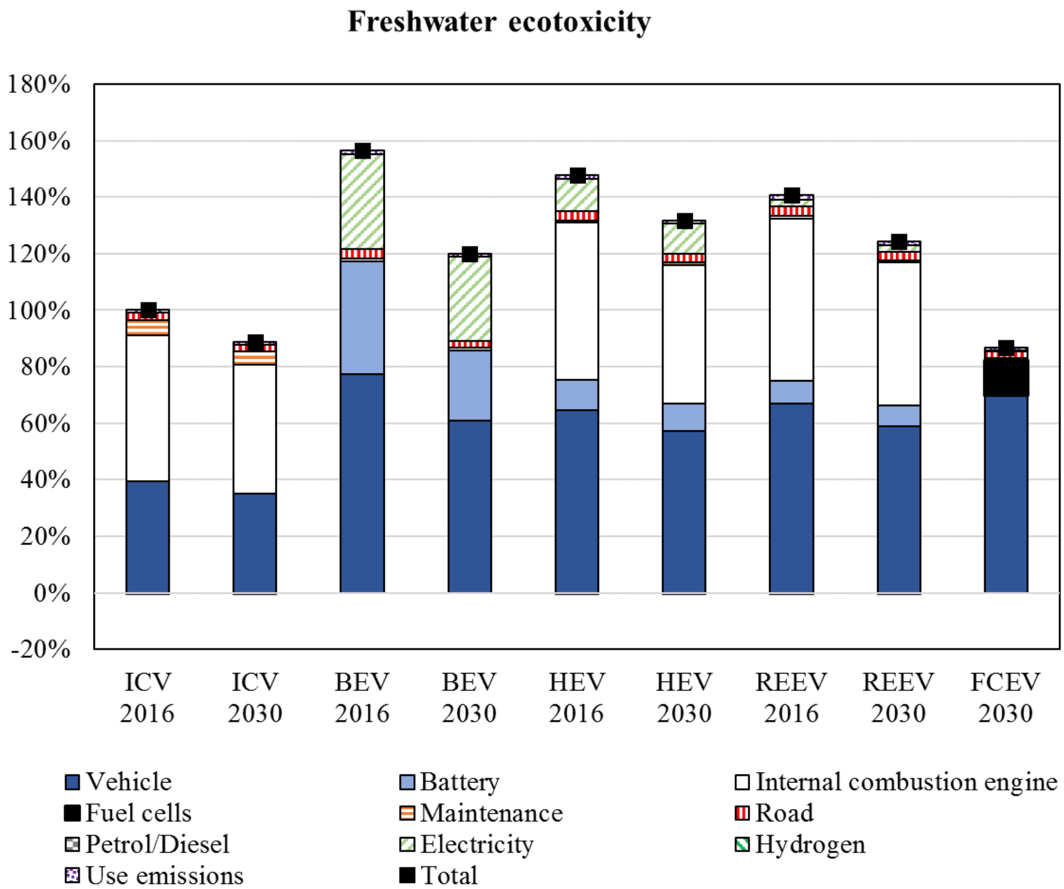

Figure S13: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories freshwater ecotoxicity. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

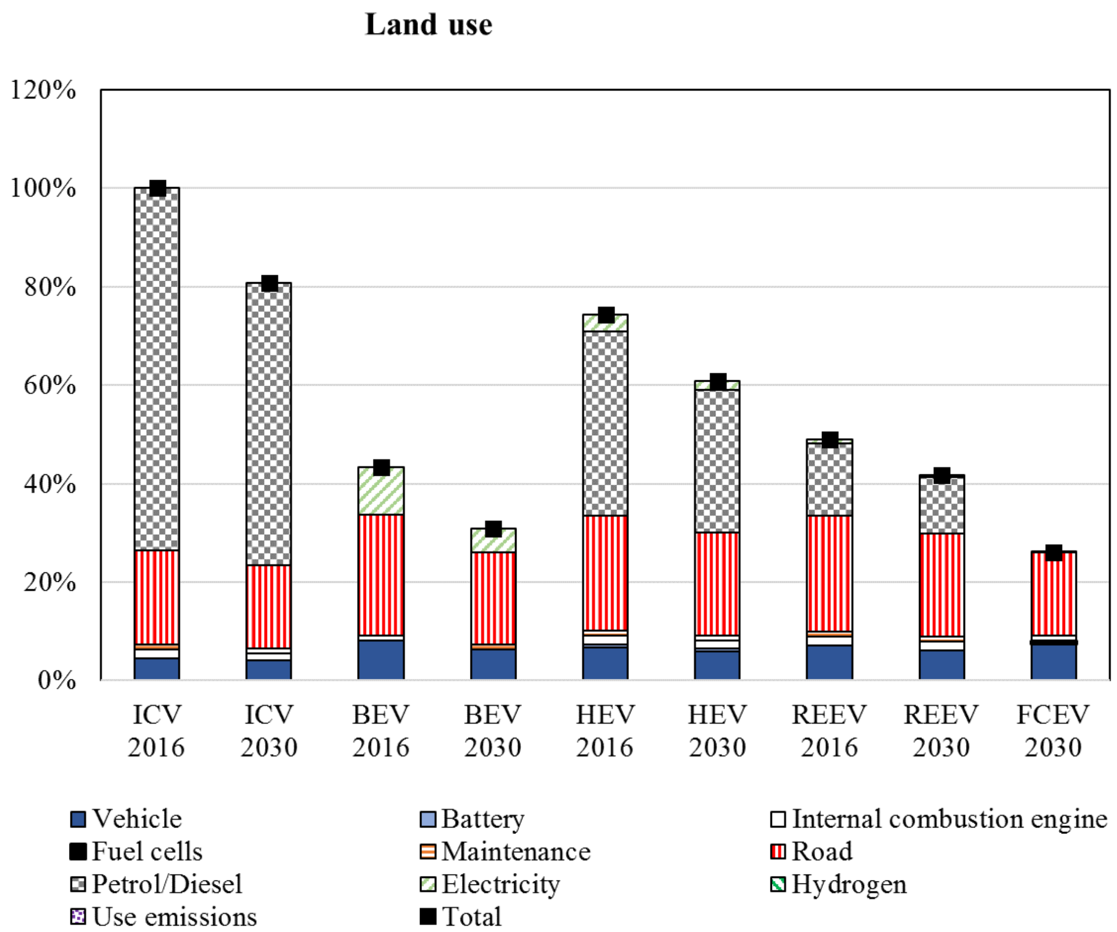

Figure S14: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories land use. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

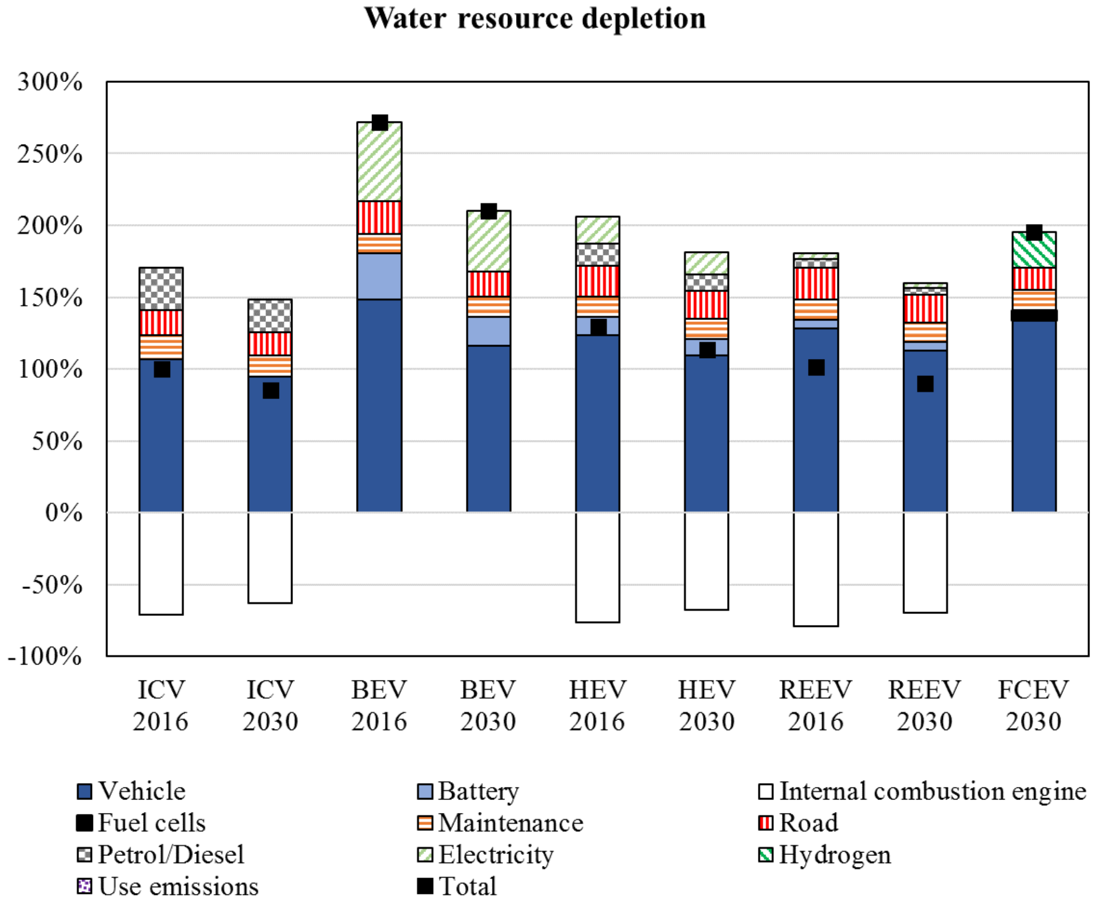

Figure S15: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories water resource depletion. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016. *It can be noticed that the internal combustion engine has a crediting in this impact category. It is due to the way Ecoinvent built one of its Aluminum production process (from the Gulf area – Area 8) in which the water used during Al production is then re-emitted in nature, but with two different processes to qualify the water. However, accounting that "pure" water is returned to nature after industrial use is currently subject to debate because of the different physical characteristics (e.g. temperature) that the water emitted can have compared to the body of the river/to the ocean, and which might have environmental impacts that are currently not accounted for in LCIA.*

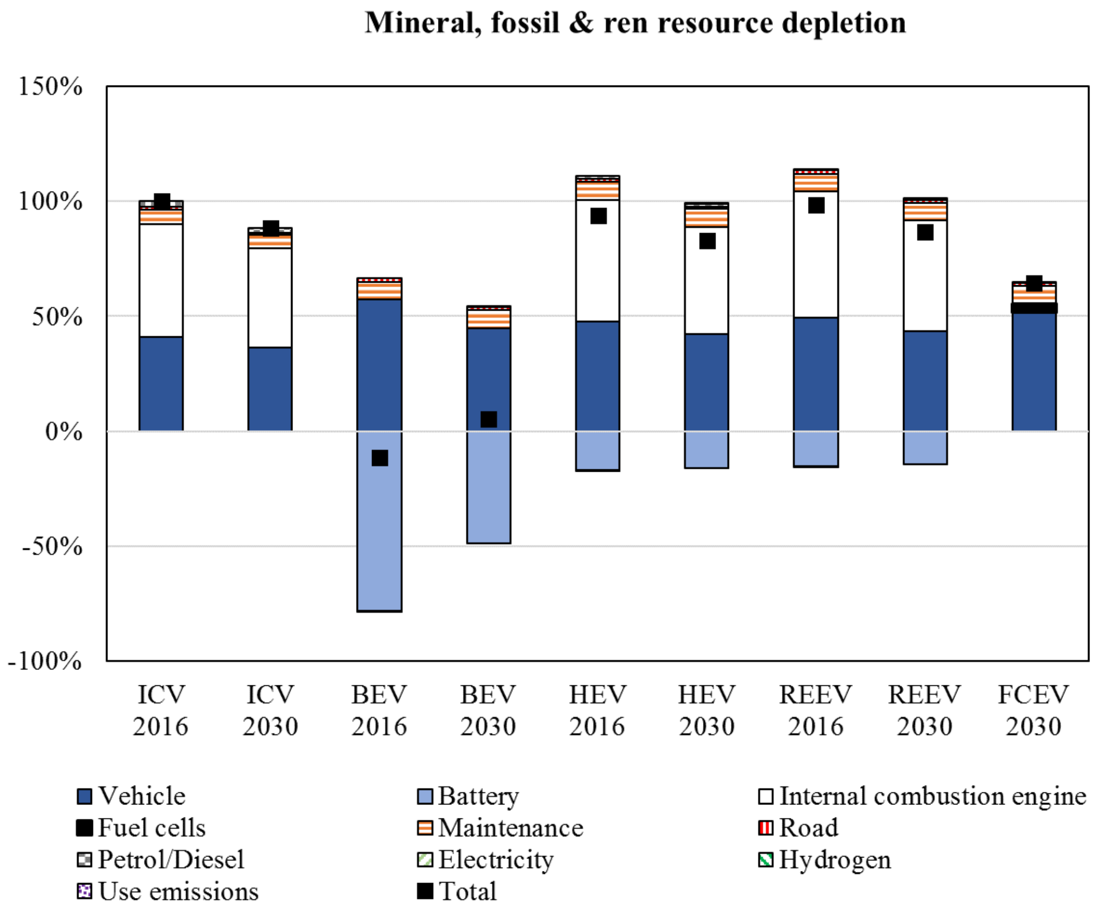

Figure S16: Comparison of the five technologies of vehicle in 2016 and 2030 based on transport of 1 km in a passenger car for the impact categories mineral, fossil and renewable resource depletion. Results are differentiated by process contribution and indexed on the impact scores obtained for internal combustion engine vehicles in 2016.

Despite the large requirements of ICVs for fossil fuels in the use stage, their contribution to resource depletion impacts is relatively small (i.e. less than 1%) compared to other resources needed in the manufacturing stage (e.g. metals for the batteries accounting for more than 90%). This bias towards metals may also be explained by some uncertainties in the LCIA method used. [3] *Likewise, batteries play an important role in the results for human toxicity impacts for BEVs, HEVs and REEVs because of the mining and production of metals, like copper, which is not fully recovered at the end-of-life of the system and induce emissions of heavy metals at different life cycle stages of the batteries. In addition to the bias in the vehicle size, these three battery-equipped vehicles (BEVs, PHEVs and REEVs) thus are associated with up to four times more human toxicity impacts than ICVs. Taking all technologies, the human toxicity impacts are driven by the manufacturing of the vehicle equipment, ranging from ca. 80% for BEVs up to 95% for ICVs and REEVs. The battery production, where emissions of copper, palladium and gold take place, contributes significantly to this trend, although the vehicle production itself, with important emissions of copper as well, generally remain the largest contribution to human toxicity impacts. For BEVs, electricity production also has an important contribution, i.e. ca. 15% in 2016, due to emissions of heavy metals from fossil fuel combustion and manufacturing of wind turbines.*

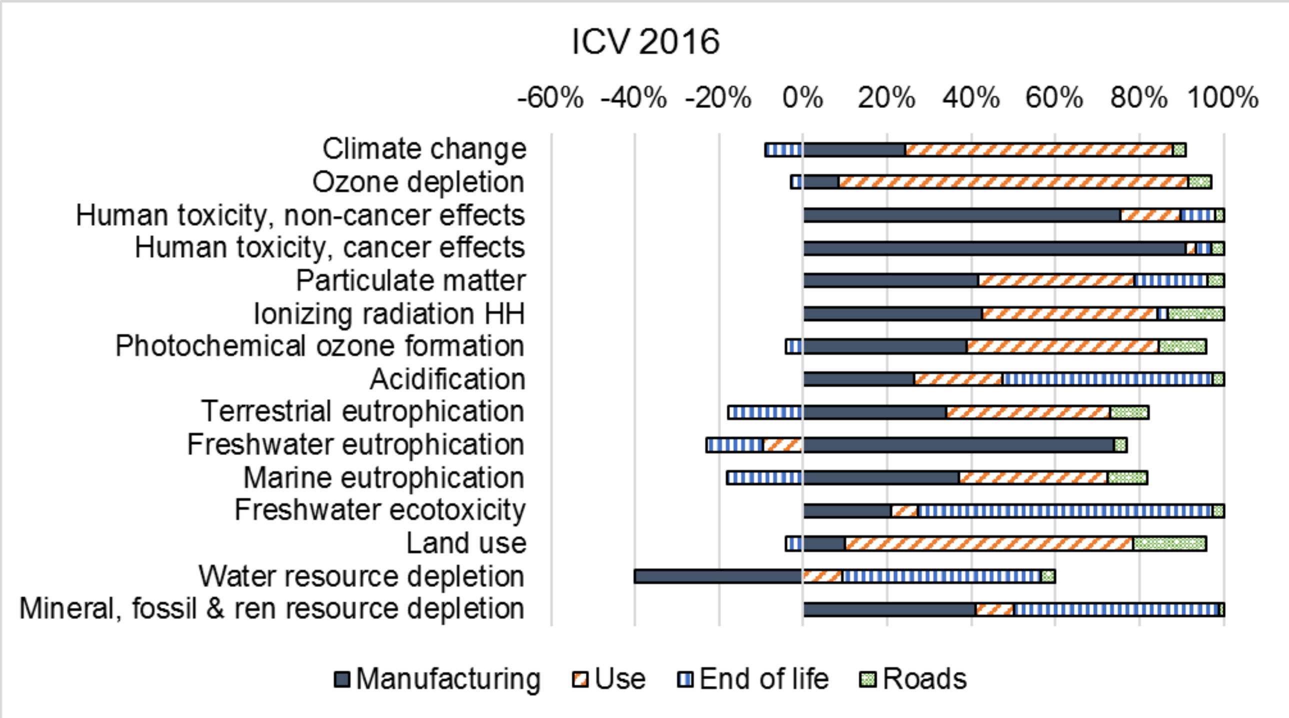

Figure S17: Contribution of the different phases of the life cycle to the 15 impact categories for the ICV in 2016

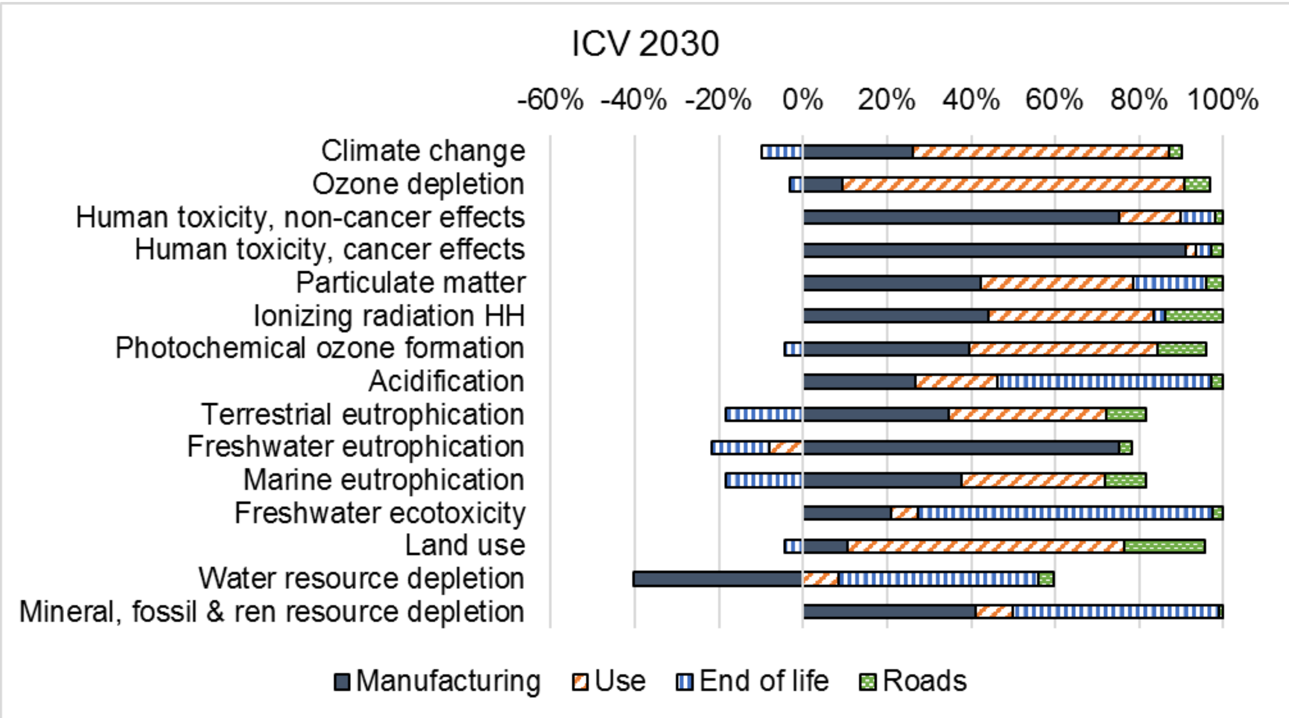

Figure S18: Contribution of the different phases of the life cycle to the 15 impact categories for the ICV in 2030

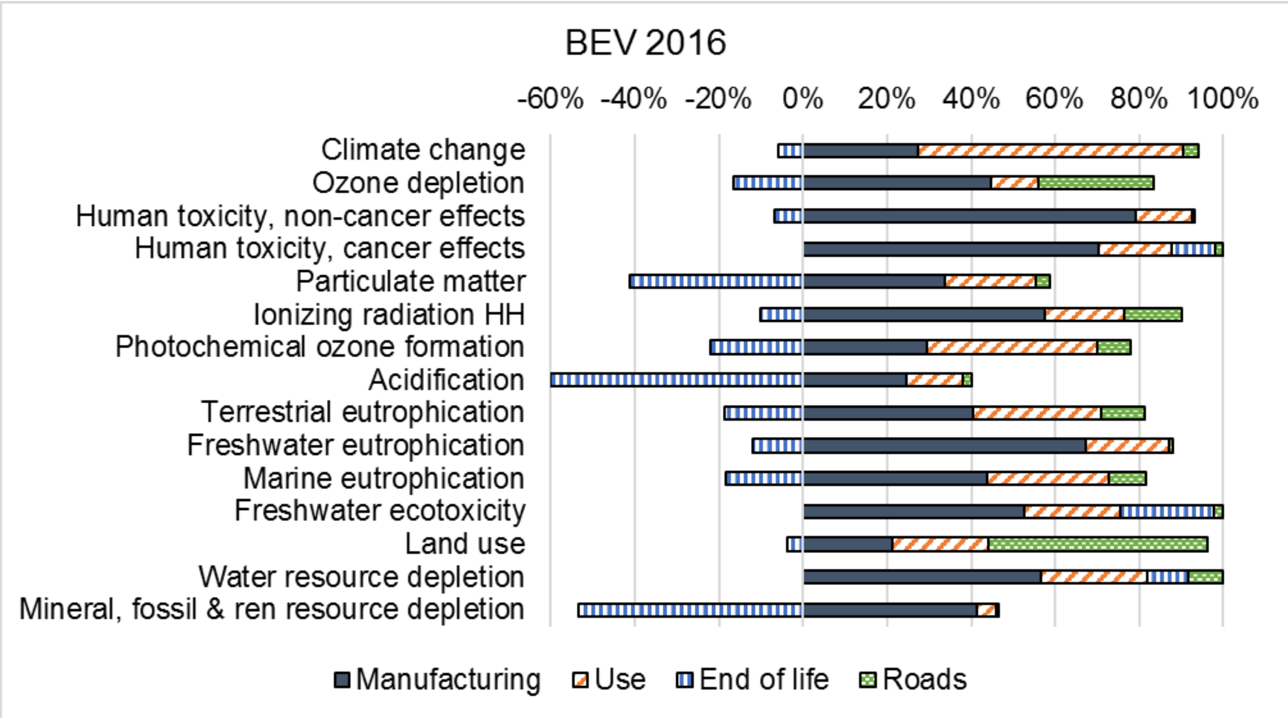

Figure S19: Contribution of the different phases of the life cycle to the 15 impact categories for the BEV in 2016

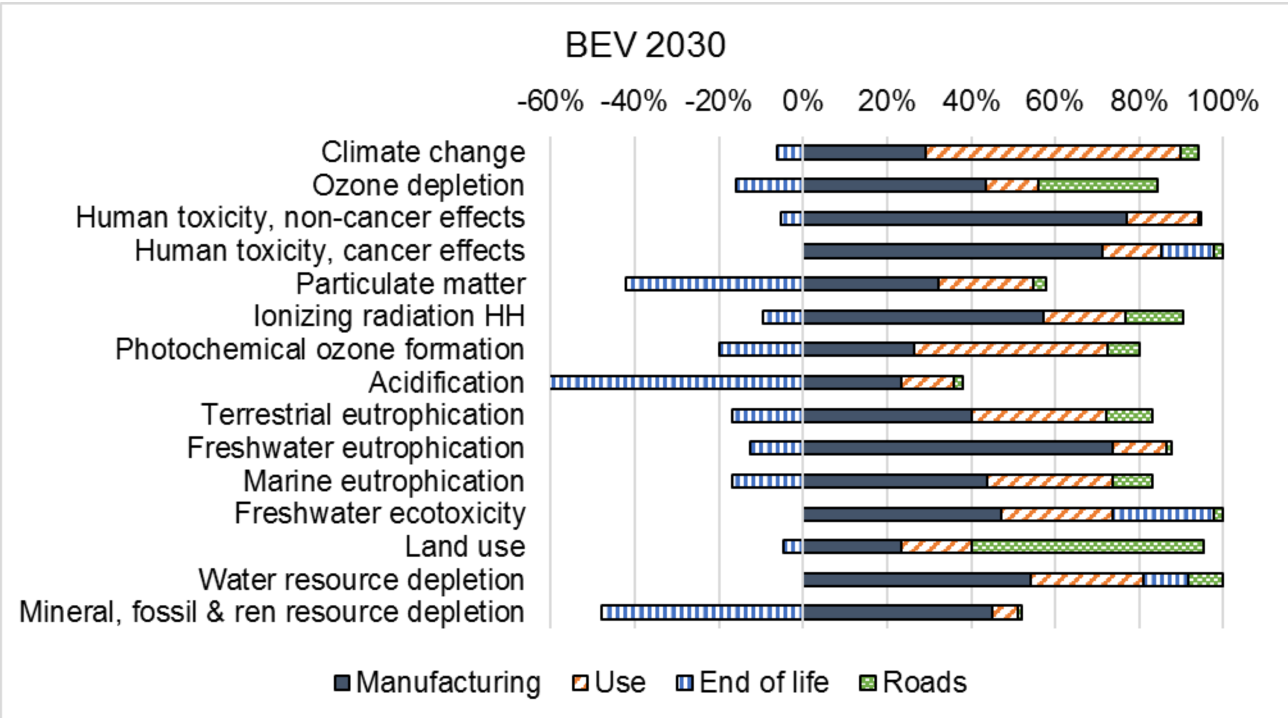

Figure S20: Contribution of the different phases of the life cycle to the 15 impact categories for the BEV in 2030

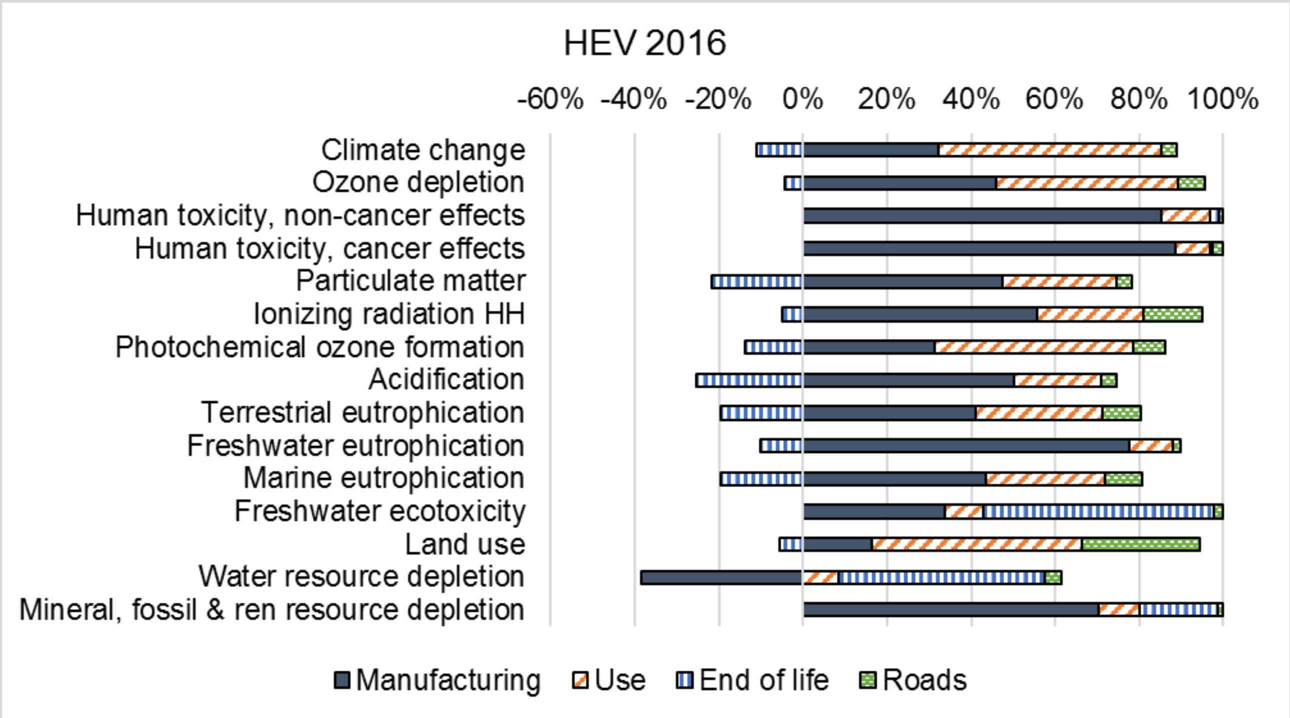

Figure S21: Contribution of the different phases of the life cycle to the 15 impact categories for the HEV in 2016

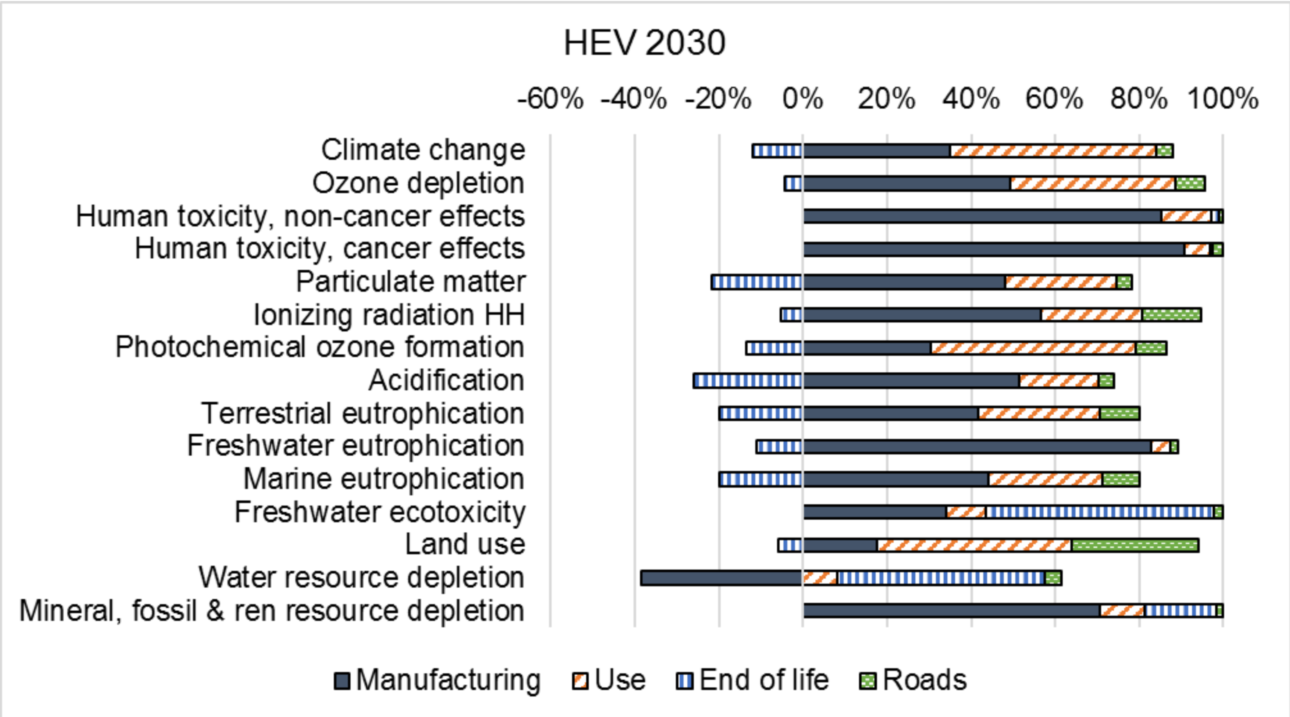

Figure S22: Contribution of the different phases of the life cycle to the 15 impact categories for the HEV in 2030

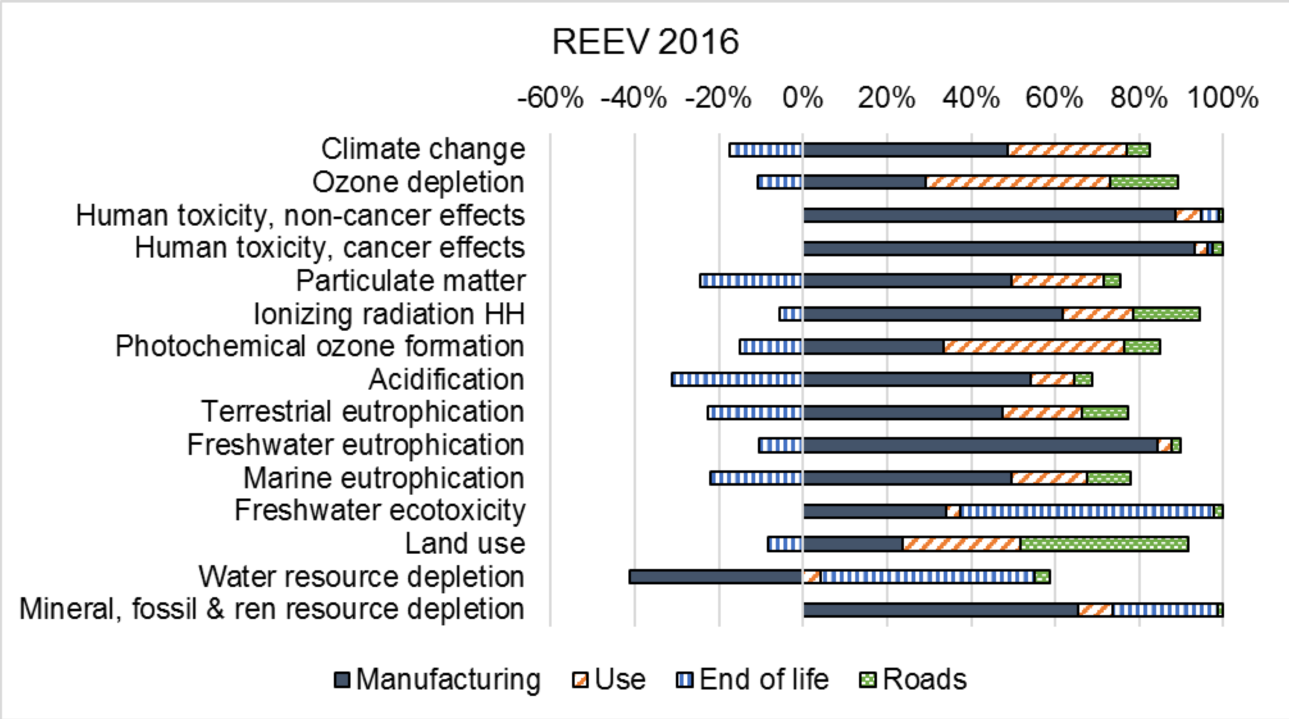

Figure S23: Contribution of the different phases of the life cycle to the 15 impact categories for the REEV in 2016

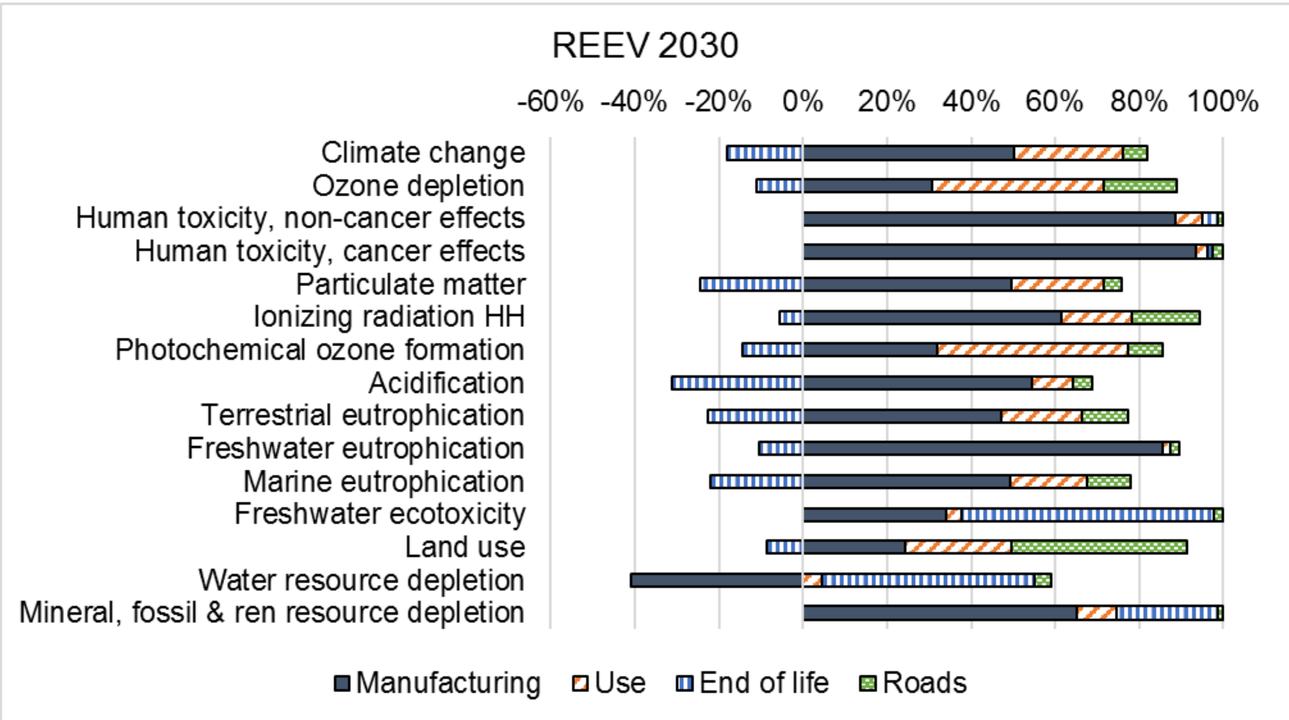

Figure S24: Contribution of the different phases of the life cycle to the 15 impact categories for the REEV in 2030

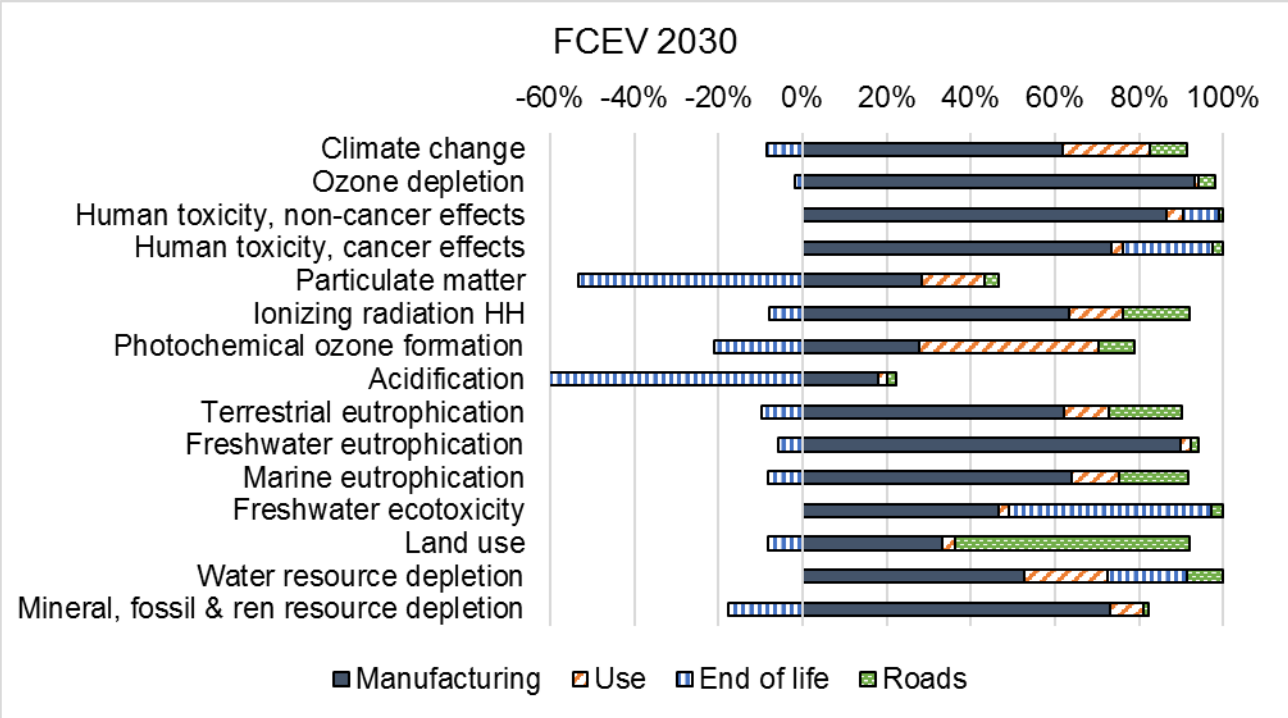

Figure S25: Contribution of the different phases of the life cycle to the 15 impact categories for the FCEV in 2030

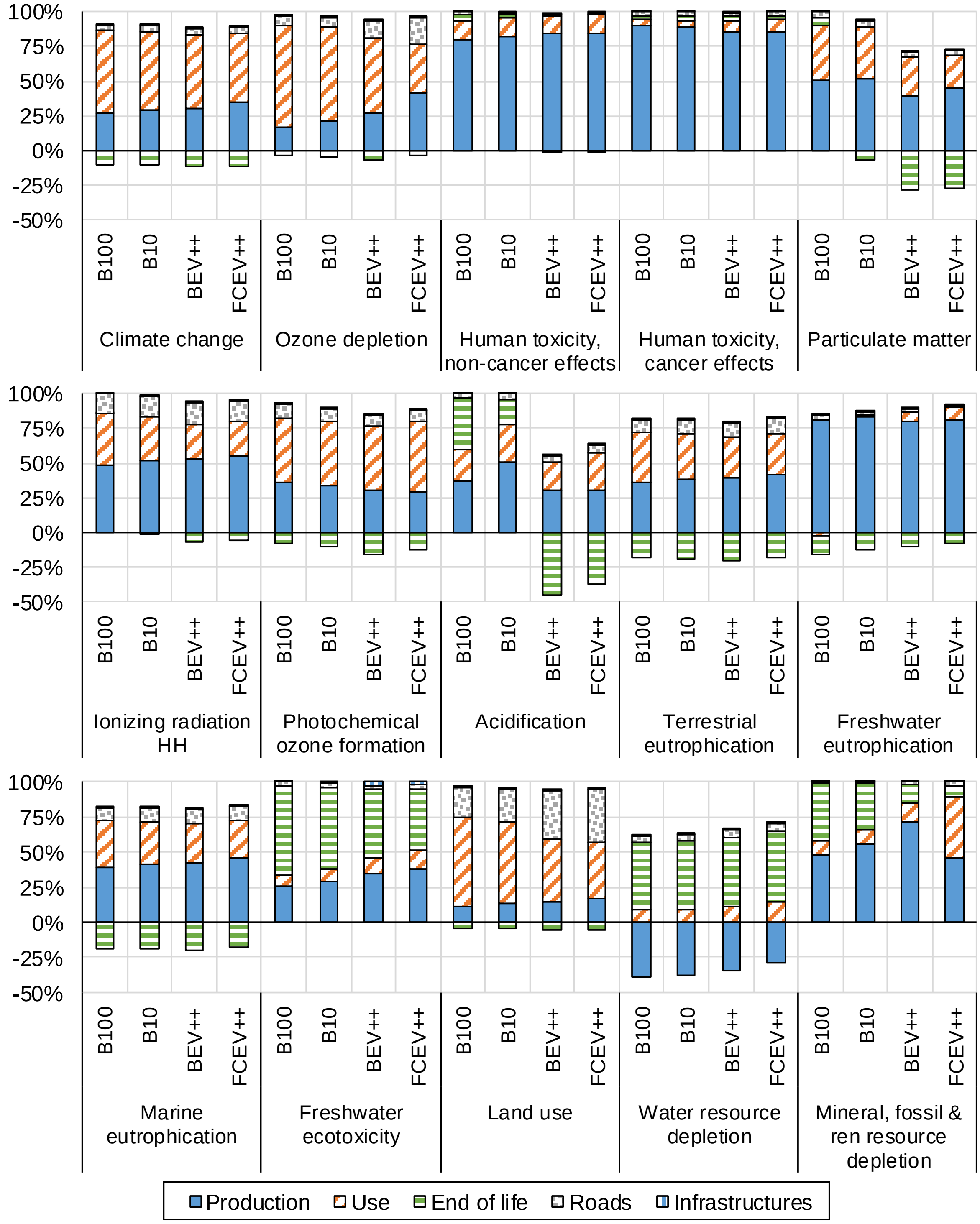

Figure S26: Impact contribution (in %) of the vehicle life cycle stages (production, use and end-of-life), the infrastructures and the roads to the cumulative midpoint impact scores from 2015 to 2030 of the scenarios B100, B10, BEV++ and FCEV++ for 15 impact categories.

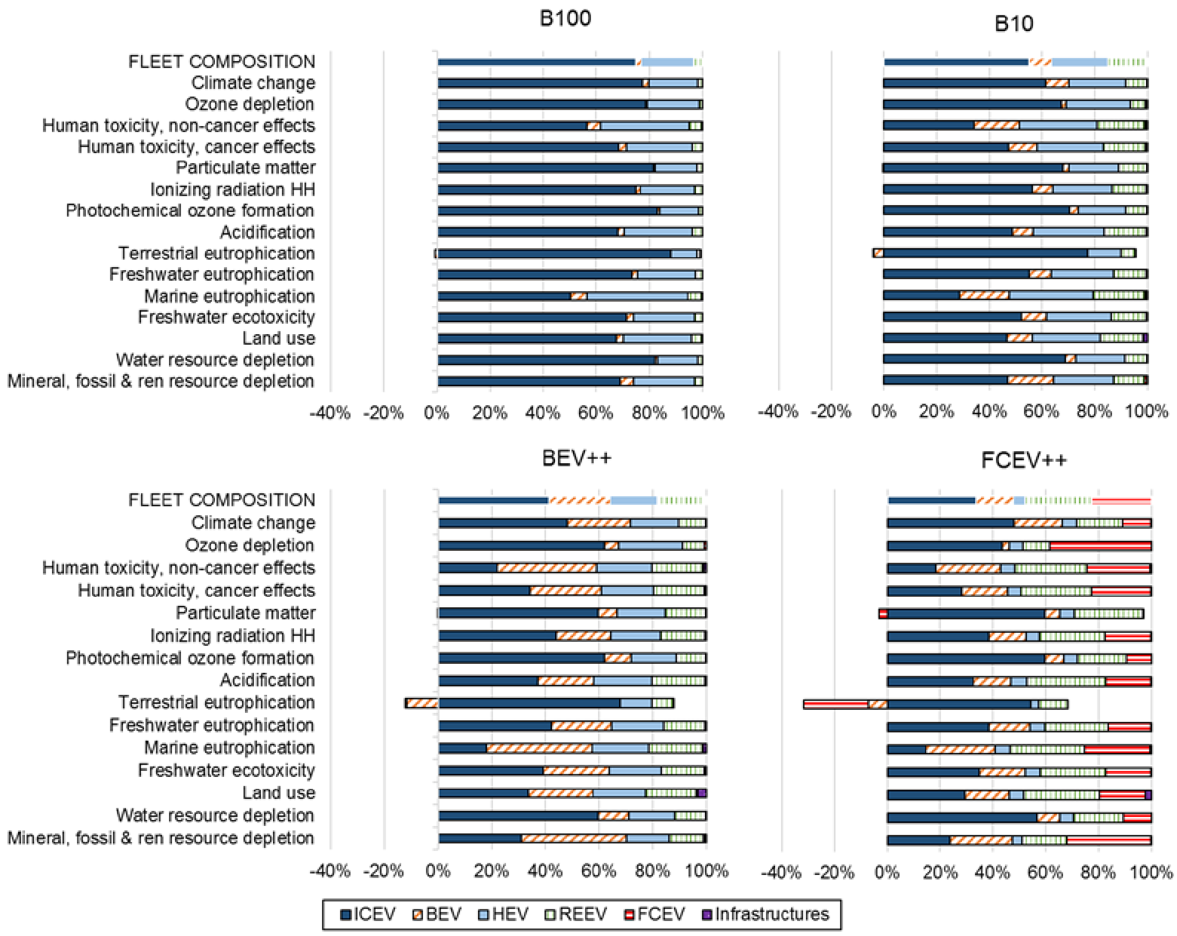

Figure S27: Contribution of the five technologies of powertrains and the infrastructures to the 15 impacts categories for the scenarios B10, B100, BEV++ and FCEV++. The first line represents the proportion of the total number of kilometers that have been driven by a specific technology during the 15 years. All the vehicles have positive scores in all the 15 categories, except BEVs and FCEVs in acidification due to the crediting of precious metals from the end of life of electrical powertrains. *This figure describes the correlation between the mileage of the different technologies and the distribution of cumulative impacts over the 15-year period. In the scenarios B10 and B100, the main contributors are ICVs, followed by HEVs. In B10, despite the implementation of the BEVs and other non-conventional vehicles, the impacts of the ICVs are found to be predominant because of the number of kilometers driven by ICVs over the whole period (more than 50%). For BEV++ and FCEV++, impact contributions are however more evenly distributed among the different powertrains because the proportion of ICVs over the 15-year period is reduced more rapidly in these scenarios. The ICVs thus take up to 30% of mileage in FCEV++ and have impact contributions fluctuating around this 30% threshold depending on the impact category. This may suggest a stronger influence of the mileage over the type of powertrain technology considered. Regardless of the scenario in place, environmental impacts of all technologies composing the fleet should therefore be considered as a whole, without limiting the efforts to specific technologies in the future market.*

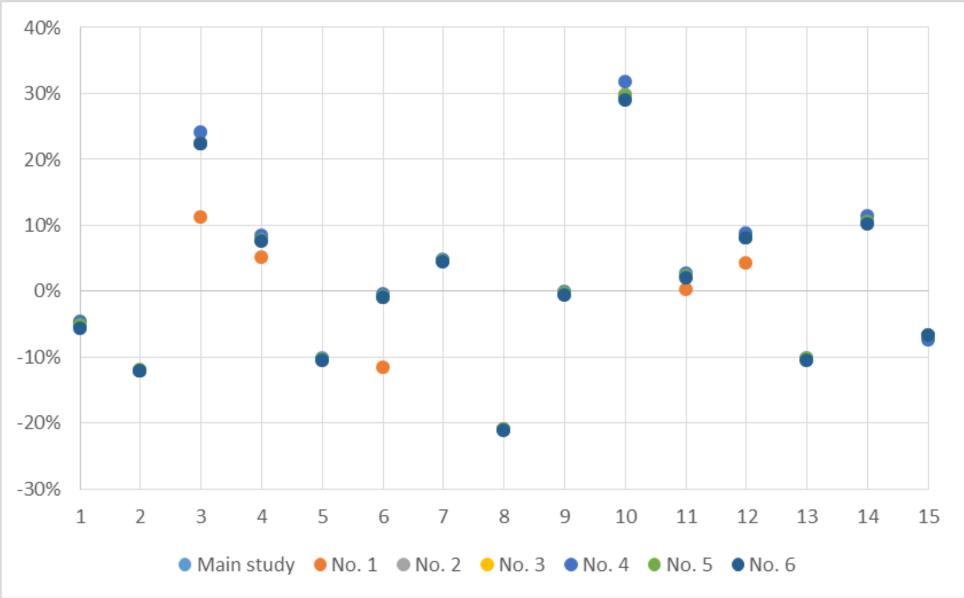

Figure S28: Results of the sensitivity analysis for scenario B10 for the 15 impact categories (1 = climate change; 2 = ozone depletion; 3 = human toxicity, non-cancer effects; 4 = human toxicity, cancer effects; 5 = particulate matter; 6 = ionizing radiation HH; 7 = photochemical ozone formation; 8 = acidification; 9 = terrestrial eutrophication; 10 = freshwater eutrophication; 11 = marine eutrophication; 12 = freshwater ecotoxicity; 13 = land use; 14 = water resource depletion; 15 = mineral, fossil and ren resource depletion).

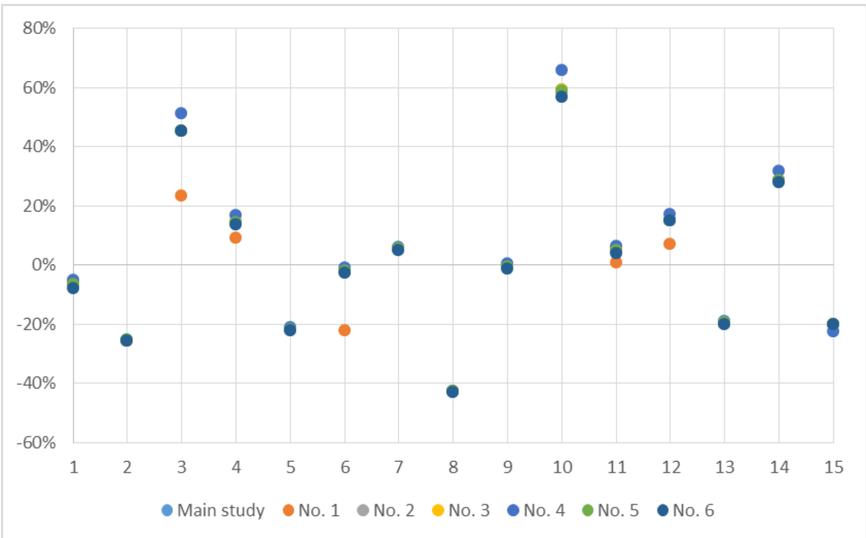

Figure S29: Results of the sensitivity analysis for scenario BEV++ for the 15 impact categories (1 = climate change; 2 = ozone depletion; 3 = human toxicity, non-cancer effects; 4 = human toxicity, cancer effects; 5 = particulate matter; 6 = ionizing radiation HH; 7 = photochemical ozone formation; 8 = acidification; 9 = terrestrial eutrophication; 10 = freshwater eutrophication; 11 = marine eutrophication; 12 = freshwater ecotoxicity; 13 = land use; 14 = water resource depletion; 15 = mineral, fossil and ren resource depletion).

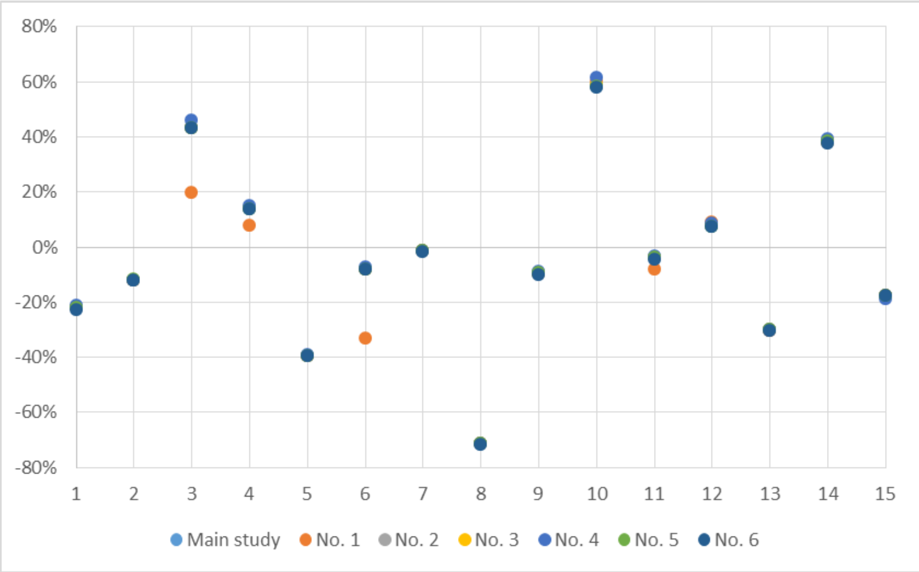

Figure S30: Results of the sensitivity analysis for scenario FCEV++ for the 15 impact categories (1 = climate change; 2 = ozone depletion; 3 = human toxicity, non-cancer effects; 4 = human toxicity, cancer effects; 5 = particulate matter; 6 = ionizing radiation HH; 7 = photochemical ozone formation; 8 = acidification; 9 = terrestrial eutrophication; 10 = freshwater eutrophication; 11 = marine eutrophication; 12 = freshwater ecotoxicity; 13 = land use; 14 = water resource depletion; 15 = mineral, fossil and ren resource depletion).

Supplementary Tables

Table S1: Characterized results in 2016 for the five technologies of powertrains

Impact category	**Unit**	**ICV**	**HEV**	**BEV**	**REEV**
Climate change	kg CO2 eq	2.61E-01	2.55E-01	2.92E-01	1.39E-01
Ozone depletion	kg CFC-11 eq	4.80E-08	4.67E-08	8.53E-09	1.62E-08
Human toxicity, non-cancer effects	CTUh	9.70E-08	2.23E-07	3.67E-07	2.06E-07
Human toxicity, cancer effects	CTUh	2.39E-08	3.45E-08	4.28E-08	3.30E-08
Particulate matter	kg PM2.5 eq	2.51E-04	1.90E-04	6.92E-05	1.56E-04
Ionizing radiation HH	kBq U235 eq	1.13E-02	1.20E-02	1.14E-02	1.03E-02
Photochemical ozone formation	kg NMVOC eq	8.52E-04	1.23E-03	9.54E-04	1.07E-03
Acidification	molc H+ eq	3.19E-03	1.44E-03	-1.05E-03	9.19E-04
Terrestrial eutrophication	molc N eq	1.74E-03	2.02E-03	1.94E-03	1.54E-03
Freshwater eutrophication	kg P eq	4.18E-05	1.33E-04	2.36E-04	1.17E-04
Marine eutrophication	kg N eq	1.52E-04	1.94E-04	2.11E-04	1.52E-04
Freshwater ecotoxicity	CTUe	9.68E+00	1.43E+01	1.52E+01	1.36E+01
Land use	kg C deficit	9.30E-01	6.91E-01	4.03E-01	4.55E-01
Water resource depletion	m3 water eq	1.64E-04	2.12E-04	4.45E-04	1.66E-04
Mineral, fossil & ren resource depletion	kg Sb eq	4.43E-05	4.16E-05	-5.09E-06	4.37E-05

Table S2: Characterized results in 2030 for the five technologies of powertrains

Impact category	**Unit**	**ICV**	**HEV**	**BEV**	**REEV**	**FCEV**
Climate change	kg CO2 eq	2.10E-01	2.03E-01	2.02E-01	1.16E-01	8.47E-02
Ozone depletion	kg CFC-11 eq	3.80E-08	3.99E-08	6.52E-09	1.35E-08	6.20E-08
Human toxicity, non-cancer effects	CTUh	8.60E-08	2.00E-07	2.68E-07	1.83E-07	1.85E-07
Human toxicity, cancer effects	CTUh	2.12E-08	3.00E-08	3.08E-08	2.90E-08	2.79E-08
Particulate matter	kg PM2.5 eq	2.19E-04	1.67E-04	4.78E-05	1.39E-04	-1.85E-05
Ionizing radiation HH	kBq U235 eq	9.62E-03	1.05E-02	8.62E-03	9.15E-03	7.44E-03
Photochemical ozone formation	kg NMVOC eq	7.42E-04	1.13E-03	8.28E-04	1.01E-03	6.66E-04
Acidification	molc H+ eq	2.77E-03	1.23E-03	-9.38E-04	8.05E-04	-2.10E-03
Terrestrial eutrophication	molc N eq	1.50E-03	1.76E-03	1.50E-03	1.38E-03	1.08E-03
Freshwater eutrophication	kg P eq	3.83E-05	1.10E-04	1.48E-04	1.02E-04	1.04E-04
Marine eutrophication	kg N eq	1.32E-04	1.69E-04	1.58E-04	1.36E-04	1.09E-04
Freshwater ecotoxicity	CTUe	8.59E+00	1.28E+01	1.16E+01	1.20E+01	8.41E+00

Land use	kg C deficit	7.50E-01	5.65E-01	2.87E-01	3.87E-01	2.51E-01
Water resource depletion	m3 water eq	1.40E-04	1.86E-04	3.43E-04	1.48E-04	3.21E-04
Mineral, fossil & ren resource depletion	kg Sb eq	3.92E-05	3.68E-05	2.38E-06	3.85E-05	2.85E-05

Table S3: Characterized results of the four scenarios in the 15 impact categories with their rankings

		Scores				**Ranking**			
Impact category	***Unit***	**B100**	**B10**	**BEV++**	**FCEV++**	**B100**	**B10**	**BEV++**	**FCEV++**
Climate change	*kg CO2 eq*	8.60E+09	8.16E+09	8.06E+09	6.71E+09	4	3	2	1
Ozone depletion	*kg CFC-11 eq*	1.55E+03	1.36E+03	1.15E+03	1.36E+03	4	3	1	2
Human toxicity, non-cancer effects	*CTUh*	4.58E+03	5.60E+03	6.65E+03	6.55E+03	1	2	4	3
Human toxicity, cancer effects	*CTUh*	9.30E+02	1.00E+03	1.06E+03	1.06E+03	1	2	4	3
Particulate matter	*kg PM2.5 eq*	8.13E+06	7.28E+06	6.35E+06	4.92E+06	4	3	2	1
Ionizing radiation HH	*kBq U235 eq*	3.95E+08	3.91E+08	3.86E+08	3.62E+08	4	3	2	1
Photochemical ozone formation	*kg NMVOC eq*	3.30E+07	3.45E+07	3.48E+07	3.25E+07	2	3	4	1
Acidification	*molc H+ eq*	9.38E+07	7.41E+07	5.37E+07	2.68E+07	4	3	2	1
Terrestrial eutrophication	*molc N eq*	6.24E+07	6.21E+07	6.20E+07	5.63E+07	4	3	2	1
Freshwater eutrophication	*kg P eq*	2.25E+06	2.92E+06	3.58E+06	3.57E+06	1	2	4	3
Marine eutrophication	*kg N eq*	5.62E+06	5.75E+06	5.89E+06	5.39E+06	2	3	4	1
Freshwater ecotoxicity	*CTUe*	3.81E+11	4.12E+11	4.38E+11	4.09E+11	1	3	4	2
Land use	*kg C deficit*	2.90E+10	2.60E+10	2.33E+10	2.02E+10	4	3	2	1
Water resource depletion	*m3 water eq*	6.21E+06	6.85E+06	7.97E+06	8.56E+06	1	2	3	4
Mineral, fossil & ren resource depletion	*kg Sb eq*	1.51E+06	1.41E+06	1.21E+06	1.24E+06	4	3	1	2

Table S4: Difference between scenarios. Formula used: DS//B100 C = (xS C-xB100 C)/xB100 C, with DS//B100 C the difference between the scenario S and the scenario B100 in the impact category C, xB100 C the score for B100 in the category C and xS C the score for S in the category C.

	B10	***BEV++***	***FCEV++***
Climate change	-5.09%	-6.33%	-22.00%
Ozone depletion	-12.18%	-25.70%	-12.20%
Human toxicity, non-cancer effects	22.33%	45.35%	43.19%

Human toxicity, cancer effects	7.74%	14.29%	13.92%
Particulate matter	-10.41%	-21.86%	-39.54%
Ionizing radiation HH	-0.94%	-2.25%	-8.18%
Photochemical ozone formation	4.55%	5.43%	-1.55%
Acidification	-21.03%	-42.73%	-71.47%
Terrestrial eutrophication	-0.42%	-0.59%	-9.64%
Freshwater eutrophication	29.68%	59.21%	58.40%
Marine eutrophication	2.25%	4.82%	-3.99%
Freshwater ecotoxicity	8.07%	14.94%	7.34%
Land use	-10.40%	-19.72%	-30.23%
Water resource depletion	10.35%	28.49%	37.93%
Mineral, fossil & ren resource depletion	-6.70%	-20.07%	-17.81%

Table S5: New difference between scenario B10 and scenario B100 for the 6 sensitivity analysis, compared to the ones from the main study.

		B10					
Impact category	Main study	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Climate change	*-5%*	-5%	-5%	-5%	-5%	-5%	-6%
Ozone depletion	*-12%*	-12%	-12%	-12%	-12%	-12%	-12%
Human toxicity, non-cancer effects	*22%*	11%	22%	22%	24%	22%	22%
Human toxicity, cancer effects	*8%*	5%	8%	8%	8%	8%	8%
Particulate matter	*-10%*	-10%	-10%	-10%	-10%	-10%	-10%
Ionizing radiation HH	*-1%*	-12%	-1%	-1%	-1%	-1%	-1%
Photochemical ozone formation	*5%*	5%	5%	5%	5%	5%	4%
Acidification	*-21%*	-21%	-21%	-21%	-21%	-21%	-21%
Terrestrial eutrophication	*0%*	0%	0%	0%	0%	0%	-1%
Freshwater eutrophication	*30%*	30%	30%	30%	32%	30%	29%
Marine eutrophication	*2%*	0%	2%	2%	3%	2%	2%
Freshwater ecotoxicity	*8%*	4%	8%	8%	9%	8%	8%
Land use	*-10%*	-10%	-10%	-10%	-10%	-10%	-11%
Water resource depletion	*10%*	10%	10%	10%	11%	10%	10%
Mineral, fossil & ren resource depletion	*-7%*	-7%	-7%	-7%	-7%	-7%	-7%

Formula used: DS//B100 C = (xS C-xB100 C)/xB100 C, with DS//B100 C the difference between the scenario S and the scenario B100 in the impact category C, xB100 C the score for B100 in the category C and xS C the score for S in the category C.

Table S6: New difference between scenario BEV++ and scenario B100 for the 6 sensitivity analysis, compared to the ones from the main study.

		BEV++					
Impact category	Main study	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Climate change	*-6%*	-6%	-6%	-6%	-5%	-7%	-8%
Ozone depletion	*-26%*	-26%	-26%	-26%	-25%	-25%	-26%
Human toxicity, non-cancer effects	*45%*	23%	45%	45%	51%	45%	45%
Human toxicity, cancer effects	*14%*	9%	14%	14%	17%	14%	14%
Particulate matter	*-22%*	-22%	-22%	-22%	-21%	-22%	-22%
Ionizing radiation HH	*-2%*	-22%	-2%	-2%	-1%	-2%	-3%
Photochemical ozone formation	*5%*	5%	5%	5%	6%	6%	5%
Acidification	*-43%*	-43%	-43%	-43%	-43%	-43%	-43%
Terrestrial eutrophication	*-1%*	-1%	-1%	-1%	0%	0%	-1%
Freshwater eutrophication	*59%*	58%	59%	59%	66%	59%	57%
Marine eutrophication	*5%*	1%	5%	5%	6%	5%	4%
Freshwater ecotoxicity	*15%*	7%	15%	15%	17%	15%	15%
Land use	*-20%*	-20%	-20%	-20%	-19%	-19%	-20%
Water resource depletion	*28%*	28%	28%	28%	32%	29%	28%
Mineral, fossil & ren resource depletion	*-20%*	-20%	-20%	-20%	-22%	-20%	-20%

Formula used: DS//B100 C = (xS C-xB100 C)/xB100 C, with DS//B100 C the difference between the scenario S and the scenario B100 in the impact category C, xB100 C the score for B100 in the category C and xS C the score for S in the category C.

Table S7: New difference between scenario FCEV++ and scenario B100 for the 6 sensitivity analysis, compared to the ones from the main study.

		FCEV++					
Impact category	Main study	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Climate change	*-22%*	-22%	-22%	-22%	-21%	-22%	-23%
Ozone depletion	*-12%*	-12%	-12%	-12%	-12%	-12%	-12%
Human toxicity, non-cancer effects	*43%*	20%	43%	43%	46%	43%	43%
Human toxicity, cancer effects	*14%*	8%	14%	14%	15%	14%	14%
Particulate matter	*-40%*	-40%	-39%	-39%	-39%	-39%	-40%
Ionizing radiation HH	*-8%*	-33%	-8%	-8%	-8%	-8%	-8%
Photochemical ozone formation	*-2%*	-2%	-1%	-2%	-1%	-1%	-2%
Acidification	*-71%*	-71%	-71%	-71%	-72%	-71%	-72%
Terrestrial eutrophication	*-10%*	-10%	-10%	-10%	-9%	-9%	-10%
Freshwater eutrophication	*58%*	60%	59%	59%	61%	58%	58%
Marine eutrophication	*-4%*	-8%	-4%	-4%	-3%	-4%	-4%

Freshwater ecotoxicity	*7%*	9%	8%	8%	8%	7%	7%
Land use	*-30%*	-30%	-30%	-30%	-30%	-30%	-30%
Water resource depletion	*38%*	38%	38%	38%	39%	38%	38%
Mineral, fossil & ren resource depletion	*-18%*	-18%	-18%	-18%	-19%	-18%	-18%

Formula used: DS//B100 C = (xS C-xB100 C)/xB100 C, with DS//B100 C the difference between the scenario S and the scenario B100 in the impact category C, xB100 C the score for B100 in the category C and xS C the score for S in the category C.

When long-term emissions are not considered (sensitivity analysis No.1), the differences between scenarios vary slightly. It impacts 6 categories out of 15: human toxicity (cancer and non-cancer effect), ionizing radiation HH, freshwater ecotoxicity and marine and freshwater eutrophication. Their scores are decreasing, which is expected since fewer emissions sources are considered, and the difference between scenarios always change in favor of the new scenarios (see Tables S5, SR and S7). This is due to the reduction of impacts of the mining processes and deposition of heavy metals on site. This impacts B10, FCEV++ and BEV++ more than B100 because in this scenario more vehicles equipped with batteries are deployed, element composed mainly by rare metals like lithium. Even though few categories are impacted, they undergo an important change, and the difference between scenarios changes by up to 25 percentage points. Thus, the way in which long-term and short-term emissions are differentiated and weighted have a substantial impact on our system.

Two other ways of calculating the number of normal charging infrastructures were tested (sensitivity analysis No. 2 and 3). The impacts of the infrastructures themselves change from 1 to 3 depending on the choice of the method. Indeed, the total number of charging stations to be installed vary of up to 200% from one method to the other. However, the contribution of the infrastructures to the final score never represent more than 2% of the final score of the impact categories. Additionally, it does not impact the difference between scenarios. It is thus clear that the infrastructure method does not influence the results even in the case of method 3, which has been developed for this paper and estimates a much higher number of infrastructures needed compared to the other methods. Even in this case, infrastructures are the smaller contributor to the results contributing for less than 1% in 14 impact categories and 2% in Freshwater Ecotoxicity. However, the different types of charging infrastructures do not change from 2016 to 2030, whereas new way of charging cars might be found and implemented with the "regular" ones (e.g. non-contact charging) which would change the impacts.

After changing the proportion of large BEV (sensitivity analysis No. 4), the results of two scenarios change very slightly and the difference between the two scenarios fluctuates of less than 2%. The system is not very sensitive to this parameter. The fuel consumption reduction rate has been increased by 10% for the sensitivity analysis No. 5. The results show that the system is not sensitive to that parameter either since the difference between the two scenarios does not experience any remarkable change. Finally, a new electricity mix has been considered to simulate a mix composed by more renewable energies in 2030 (sensitivity No.6). Just as for the other parameters, the change of the electricity mix has a small influence on the difference between scenarios (1% or less, depending on the impact category).

All in all, each tested input parameter present no impacts on the results of the study. The system has numerous input parameters which have a considerable inertia since making them vary individually hardly influence the results. A great majority of the errors present in one scenario are also present in the other one and thus compensate each other. This is explained by the fact that the two scenarios are composed by the same elements (the five types of vehicles and the three types of charging infrastructures), but in different quantities, which leads to a system with a low sensitivity in general. Consequently, the system can be considered as very robust, and even a small percentage of difference gives a real advantage to one of the scenarios.

Supporting Methods

1. Decision context and multi-processes modeling

The decision-context influences the way the co-products are handled in the impact assessment. Because of the effects the development of these technologies can have on electricity generation, fossil-fuel consumption and rare resources use in industry, decision-context is a macro level decision support (situation B per [4]). Thus, a consequential approach is used and system expansion is considered for the multi-processes modeling, meaning that the additional functions related to co-products are integrated in the system boundaries.

2. System modeling and calculations

2.1. Main hypothesis

Only passenger vehicles are considered.
The zone under study is called zone Z in this document and corresponds to the two provinces of København Omegn and København By.

2.2. Distance driven per year per technology of powertrain (scenarios contruction)

DATA:
Population today in Zone Z: P_0 = 1 275 332 [capita] [5]
Projected population in Zone Z in year y: P_y

Table S8: Data used for the population in Zone Z [5]

Year	P_y [capita]
2016	1292205
2017	1314235
2018	1331477
2019	1347742
2020	1363391
2021	1378786
2022	1393985
2023	1408815
2024	1423229
2025	1437167
2026	1450563
2027	1463368
2028	1475559
2029	1487122
2030	1498043

Average daily transport by passenger car in København Hovedstaden (capital region):
$D_{PV\ hovedstaden}$ = 4,87 [km/capita/day] [6]

Scenario B10 and B100 are inspired from McKinsey&co report[7] and scenarios BEV++ and FCEV++ are explorative scenarios built for this study. The main quantitative assumptions of McKinsey&co report[7] are available in Table S9. The proportions of the different vehicles along the years can be found in Tables S10 to S13 and is illustrated in Figure S31.

Table S9: Main quantitative assumptions of McKinsey&co report (retrieved from the text of the report)[7].

Scenario	General	ICV	BEV	HEV/REEV	FCEV
B100	Leading to a dual (electric/ mechanical) powertrain scenario	Dominant until 2030+	Become economically competitive after 2030	Dominant in 2035, and slowly replaces ICV	No infrastructure so no FCEV
B10	Leading to a BEV and FCEV world from 2035+	Dominant until 2025	Become dominant in smaller vehicles in long term	Bridging technology	Become dominant in larger vehicles in long term

Vehicle distribution in scenario i (year y) for technology T: $x_{T\ y\ i}$ [%]
For example: proportion of BEVs in year 2020 in scenario B10: $x_{BEV\ 2020\ B10}$

Table S10: Proportion of the different types of vehicles used for Scenario B100 (scenario inspired by McKinsey&co[7]).

y	**$x_{ICV\ y\ B100}$ [%]**	**$X_{BEV\ y\ B100}$ [%]**	**$X_{HEV\ y\ B100}$ [%]**	**$X_{REEV\ y\ B100}$ [%]**	**$X_{FCEV\ y\ B100}$ [%]**
2015	99,5	0,3	0,2	0	0
2016	98,5	0,6	0,9	0	0
2017	97,4	0,6	2	0	0
2018	94,4	0,6	5	0	0
2019	90,4	0,6	9	0	0
2020	87,4	0,6	12	0	0
2021	83,9	0,6	15	0,5	0
2022	80	1	18	1	0
2023	76,5	1,5	20	2	0
2024	72,5	2	22,5	3	0
2025	68	3	25	4	0
2026	63,5	3,5	28	5	0
2027	60	4	30	6	0
2028	56,5	4,5	32	7	0
2029	53,5	4,5	34	8	0
2030	50	5	36	9	0

Table S11: Proportion of the different types of vehicles used for Scenario B10 (scenario inspired by McKinsey&co[7]**)**

y	**$X_{ICV\ y\ B10}$ [%]**	**$X_{BEV\ y\ B10}$ [%]**	**$X_{HEV\ y\ B10}$ [%]**	**$X_{REEV\ y\ B10}$ [%]**	**$X_{FCEV\ y\ B10}$ [%]**
2015	99,5	0,3	0,2	0	0
2016	98,5	0,6	0,9	0	0
2017	94,5	1	3	1,5	0
2018	88,5	2	7	2,5	0
2019	80	3,5	13	3,5	0
2020	72,5	4,5	18	5	0
2021	66	5	22	7	0
2022	58,5	6	26,5	9	0
2023	52	7	28	13	0
2024	46,5	8	29,5	16	0
2025	41	9	30	20	0
2026	36,5	11	29,5	23	0
2027	32,5	13	29	25	0,5
2028	29	16	27	27	1

2029	25	19	26	28	2
2030	22	22	24	29	3

Table S12: Proportion of the different types of vehicles used for Scenario BEV++.

y	**$X_{ICV\ y\ BEV++}$ [%]**	**$X_{BEV\ y\ BEV++}$ [%]**	**$X_{HEV\ y\ BEV++}$ [%]**	**$X_{REEV\ y\ BEV++}$ [%]**	**$X_{FCEV\ y\ BEV++}$ [%]**
2015	99,5	0,3	0,2	0	0
2016	98,9	0,6	0,5	0	0
2017	94,5	1	3	1,5	0
2018	87,5	3	7	2,5	0
2019	78	5	13	4	0
2020	68	8	18	6	0
2021	57	12	22	9	0
2022	46	16	25	13	0
2023	37,5	19,5	26	17	0
2024	28	24	26	22	0
2025	20	30	25	25	0
2026	13	35	24	28	0
2027	6,5	39	22	32	0,5
2028	5	43	18	33	1
2029	2	47	15	34	2
2030	2	49	12	34	3

Table S13: Proportion of the different types of vehicles used for Scenario FCEV++.

y	**$X_{ICV\ y\ FCEV++}$ [%]**	**$X_{BEV\ y\ FCEV++}$ [%]**	**$X_{HEV\ y\ FCEV++}$ [%]**	**$X_{REEV\ y\ FCEV++}$ [%]**	**$X_{FCEV\ y\ FCEV++}$ [%]**
2015	99,5	0,3	0,2	0	0
2016	98,9	0,6	0,5	0	0
2017	96,5	1,5	1,5	0,5	0
2018	90	3	4	3	0
2019	76,5	7	8	8	0,5
2020	59	12	11	15	3
2021	40	15	13	25	7
2022	27	17	12	32	12
2023	19	18	9	37	17
2024	13	18,5	4,5	39	25
2025	6,5	18,5	2	40	33
2026	2,5	19	0,5	40	38
2027	0	19	0	38	43
2028	0	19,5	0	34	46,5
2029	0	20	0	30,5	49,5
2030	0	21	0	27	52

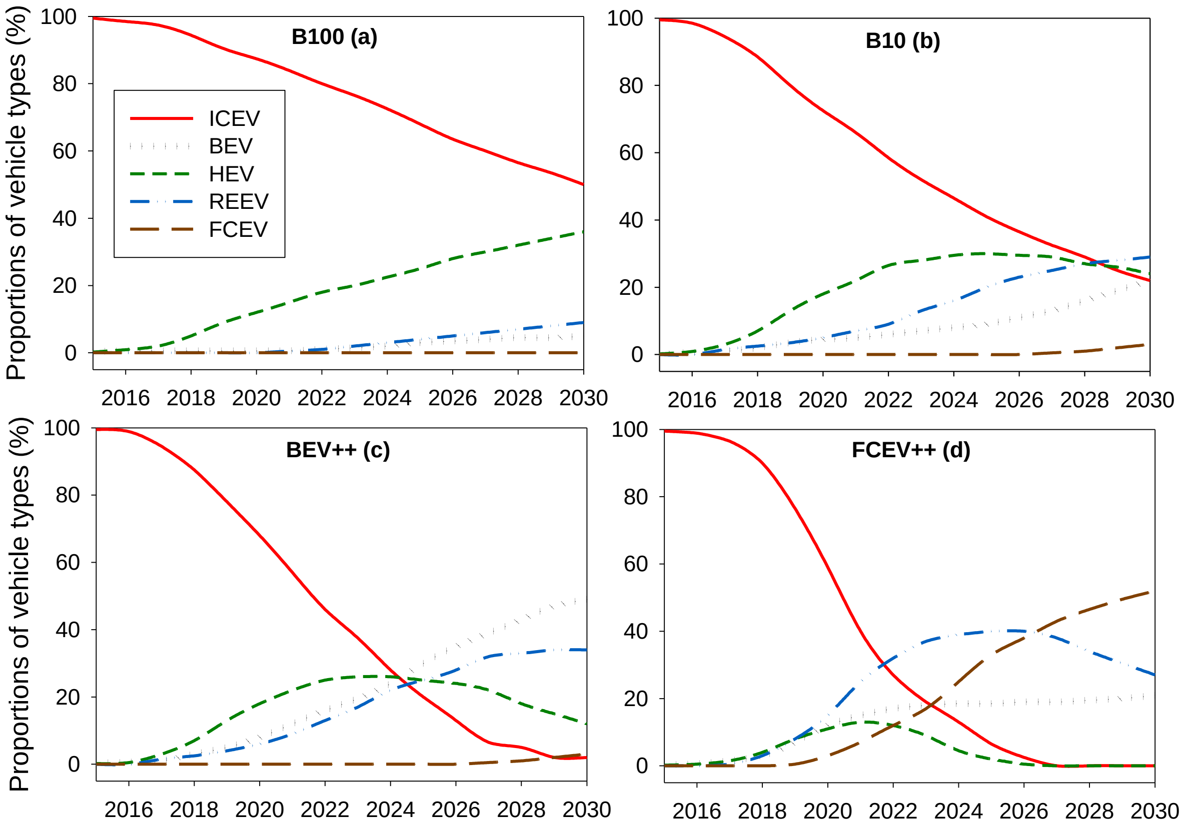

Figure S31: Global market shares (% of the fleet) from 2015 to 2030 by powertrain technology for the 4 considered scenarios: B10 (a), B100 (b), BEV++ (c) and FCEV++ (d).

CALCULATIONS:

The daily transport of Zone Z is approximated by the daily transport in København Hovedstaden.

Average daily transport by passenger car in Zone Z:

$D_{PV} = D_{PV\ hovedstaden}$= 4,87 [km/capita/day]

The distance driven per day is considered constant between today and 2030, and the number of passenger per car too.

Total distance driven with all passenger cars in Zone Z in the entire year y:

$$D_{TOT\ y} = D_{PV\ hovedstaden} * P_y * 365 \text{ [km/year]}$$

Total distance driven with technology T in Zone Z in the entire year y in scenario i:

$$D_{T\ y} = D_{TOT\ y} * x_{T\ y\ i} \text{ [km/year]}$$

2.3. Modeling of the vehicles

A model M is defined by:

- A technology T (ICV, BEV, HEV, REEV or FCEV)
- A period (t1: 2015-2020, t2: 2020-2025 or t3: 2025-2030)
- In some cases, a type of vehicle (only for BEV and HEV)

General parameters defining the models:

Average curb mass of a vehicle of model M: m_M [kg]

Average fuel consumption of a vehicle of model M: FC_M [L/km, kWh/km or kg H_2/km]

Life of a vehicle of model M: L_M [km]

Average weight of the battery of a vehicle of model M: mb_M [kg]

Average battery capacity of a vehicle of model M: BC_M [kg]

Life of the battery of a vehicle of model M: Lb_M [km]
Power of fuel cells needed: Pfc [kWh]
Proportion of type A within the model M: $P_{A\ M}$ [%]

Table S14: Characteristics of the different technologies:

Category	Combustion engine	Electric motor	Battery	Fuel-cells
ICV	x			
BEV		x	Li-ion	
HEV	x	x	NiMH for HEV Li-ion for PHEV	
REEV	x*	x	Li-ion	
FCEV		x		x

*: acting as a generator to recharge the battery when it is depleted.

The method used to define the models is the following:
(1) A base model for the year 2016-2020 (t1) is defined, preferably base on real world data, preferably on the Danish market.
(2) Hypothesis are applied to the different parameters of the models to define them on the other periods of time (t2=2021-2025 and t3=2026-2030).

ICV base-model is inspired by data from [8], which contains the average characteristics of the cars sold in Denmark since 2009, by year. A private vehicle having an average lifetime of 10 years [9], the average over the whole period of time available in [8] is a good approximation of the average characteristics of the current vehicles driving on the Danish roads. Concerning BEV base-model, Dansk Elbil Alliance and Danske Bilimportører have given us data about the exact composition of the BEV fleet in Copenhagen per model of vehicle. Complementary information related to the models has been retrieved from the official manufacturers' brochures. A factor has been applied on the fuel consumption based of recent studies highlighting the important difference between theoretical data and real-life consumption [10]**.** Moreover, a constant has been added to traduce the need of externalities (heat, air-conditioning, radio and lights) that electric vehicles undergo. The need of additional heating is due to the very low heat loss of electric motors compared to conventional vehicles, and as a matter of fact, heating is indispensable almost permanently in Denmark. The HEV, REEV and FCEV base-models are inspired by the BEV base-model since these technologies are barely present in the Danish market today.

2.3.1. Concerning all models

DATA:
Lifetime of the vehicles: $L_{SimaPro}$ = 150000 [km] (Ecoinvent v.3.1)
Lifetime of the batteries: $Lb_{SimaPro}$ = 100000 [km] (Ecoinvent v.3.1)
Vehicles weight reduction rate per year: D_m = 1,2 [%] [11]
Fuel consumption reduction rate per year: D_{FC} = 2,5 [%] [12]
Electricity consumption reduction rate per year: D_{EC} = 1,25 [%] [12]
Additional energy use due to real-world driving and air conditioning for ICE: μ = 21 [%] [8]
Additional energy use due to real-world driving for electric motors: α = 15 [%]
Additional energy use due to safety and comfort for electric motors: α_{SC} = 0,054 [kWh/km] [10]
Average battery density in 2015: BD_{2015} = 114 [Wh/kg] (Ecoinvent v3.1)
Average battery density in 2020: BD_{2020} = 235 [Wh/kg] [13]
Average battery capacity in 2015: BC_{2015} = 23,5 [kWh] [12]
Average battery capacity in 2020: BC_{2020} = 45 [kWh] [12]

In 2015, the battery density is different for the Large and the Small-Medium model. This is because the large model (Tesla) uses a more sophisticated technology of battery cell, since batteries are still an under-development technology. However, the technology will stabilize during the next years to come, and there will be no difference in the average technology between large and small vehicles. Therefore, the same predicted battery density is used in 2021.

CALCULATIONS:

Vehicle lifetime:
The life time of the vehicles is assumed to be the same for all the models of vehicles and stays constant through the years (even though it is differentiated for the components such as the battery).
$L_M = L_{SimaPro}, \forall M.$

Battery lifetime:
The life time of the batteries is supposed to be the same for all the models of vehicles that have a battery and stays constant through the years.
$Lb_M = Lb_{SimaPro}, \forall M.$

Vehicles weight:
The weight of the vehicles is assumed to decrease every year thanks to technology improvements and the rate of decrease is the same for all types of fuel and stays constant through the years.

$m_{M\ t2} = m_{M\ t1} * (1-D_m)^5$

$m_{M\ t3} = m_{M\ t1} * (1-D_m)^{10}$

Fuel consumption:
The fuel and electricity consumption decreases every year thanks to technology improvements and the rate of decrease is the same for all types of fuel and stays constant through the years.

$FC_{M\ t2} = FC_{M\ t1} * (1-D_{FC})^5$

$FC_{M\ t3} = FC_{M\ t1} * (1-D_{FC})^{10}$

$EC_{M\ t2} = EC_{M\ t1} * (1-D_{EC})^5$

$EC_{M\ t3} = EC_{M\ t1} * (1-D_{EC})^{10}$

Due to factors like occupancy rate, type deflation, driving behavior and air conditioning, the real-world fossil-fuel consumption differs from the theoretical one with the NEDC cycle. These factors are gathered in a rate to apply to fuel consumption.

$FC_{real\ M} = (1+\mu)*FC_M$

Due to factors like occupancy rate, type deflation and driving behavior, the real-world electricity consumption differs from the theoretical one with the NEDC cycle. Additionally, the heating, the air conditioning and the radio, lights, etc, consume more electricity. This is gathered in a constant per km (they are considered to work 0,83%, 0,04% and 33% of the time respectively).

$EC_{real\ M} = (1+\alpha)*FC_M + \alpha_{SC}$

Remark: this constant concerns only BEVs, which has no thermal motor at all, and thus needs to produce heat separately.

Battery weight:
Thanks to technology improvements, battery density is likely to increase soon and stay constant from 2021. At the same time, the capacity of the battery on board vehicles will increase [12].
Thus, the battery decrease rate from 2016 to 2020 is the following:

$D_{BW}=1- (BC_{2020}/BD_{2020})/ (BC_{2015}/BD_{2015})$

The reduction in the size of the battery and the vehicle are assumed to be comparable in the US and in the EU.
Therefore, the weight of the future batteries is defined by:

$m_{M\ t2} = m_{M\ t1} * (1-D_{BW})$

$m_{M\ t3} = m_{M\ t2}$

2.3.2. ICVs
Differentiated by period: ICV_t1, ICEV_t2 and ICV_t3.

The averaged data concerning vehicles sold in Denmark the last 13 years represents the average passenger vehicle present on the roads today, and thus the average current ICV since this technology represents more than 98% of the market right now.

BASE MODEL (ICV_t1): average passenger vehicle on the roads today using data from [8].
This defines the following variables: $m_{ICV\ t1}$ and $FC_{ICV\ t1}$.

The assumption is made that the proportion of Diesel vs Petrol/NG vehicles does not vary through the years.
Proportion of vehicles using diesel: P_{diesel} = 30 [%] [14]
Proportion of vehicles using gasoline or natural gas: $P_{petrol/NG}$ = 70 [%] [14]

Table S15: Characteristics of the time-differentiated ICV models.

Parameters	*Unit*	*Value*		
		2016-2020	*2021-2025*	*2026-2030*
m tot	kg	1.29E+03	1.22E+03	1.14E+03
m_glider	kg	9.40E+02		
m_ICE	kg	3.51E+02		
FC	L/km	5.90E-02	5.20E-02	4.58E-02
FC_real	L/km	7.14E-02	6.29E-02	5.54E-02
L	km	1.50E+05	1.50E+05	1.50E+05

2.3.3. BEVs

Differentiated by period (t1, t2 and t3) and size (Small-Medium and Large): BEV_S-M_t1, BEV_S-M _t2 and BEV_S-M _t3, and BEV_L_t1, BEV_L _t2 and BEV_L _t3.

BASE MODEL (BEV_S-M_t1 and BEV_L_t1): average electric vehicles on the roads today. The category Large represents vehicles that have more than 50kW of power <u>and</u> more than 200 kWh of battery capacity (Dansk Energy, personal communication, 01/02/2016).
This defines the following variables: $m_{BEV\ SM\ t1}$, $FC_{BEV\ SM\ t1}$, $BC_{BEV\ SM\ t1}$, $m_{BEV\ L\ t1}$, $FC_{BEV\ L\ t1,}$ $mb_{BEV\ L\ t1}$, $BC_{BEV\ SM\ t1}$, $P_{S\text{-}M\ BEV}$ and $P_{L\ BEV}$.

Battery weight:
The battery weight of the S-M BEV is not available from the data, but the capacity is. Thus:

$$mb_{BEV\ SM\ t1} = BC_{S\text{-}M\ BEV\ t1} / BD_{2015} * 1000$$

It is assumed that all the electric vehicles considered are equipped with Li-ion batteries.

Proportion of small-medium and large vehicles
The current repartition between large and small-medium models is mainly due to the absence of taxes for electric vehicles today in Denmark. Therefore, it is highly advantageous to buy a large/sport EV compared to the same model with combustion engine. However, from 2016, EVs begin to be taxed little by little until reaching the same level of tax than ICEV in 2020. It is then less and less interesting to buy large EVs. Additionally, according to Dansk Energy, small EVs will have the user same cost than a small ICEV from 2020. Therefore, the repartition between small-medium and large BEVs is very likely to get closer to the general trends (only 10% of the vehicles are luxury ones and upper). For this reason, an evolution of the repartition between the “small-medium” and the “large” category is considered.

Table S16: Characteristics of the time-differentiated BEV models.

Parameter	*Unit*	*Value*					
		2016-2020		*2021-2025*		*2026-2030*	
		S-M	*L*	*S-M*	*L*	*S-M*	*L*
P	%	*55%*	*45%*	*60%*	*40%*	*65%*	*35%*
m_tot	kg	1.37E+03	2.10E+03	1.29E+03	1.98E+03	1.21E+03	1.86E+03
m_glider	kg	1.06E+03	1.42E+03	9.98E+02	1.35E+03	9.30E+02	1.24E+03
m_EP	kg	1.01E+02	1.36E+02	9.51E+01	1.28E+02	8.86E+01	1.18E+02
EC	kWh/km	1.50E-01	1.99E-01	1.41E-01	1.87E-01	1.32E-01	1.75E-01
EC_real	kWh/km	2.27E-01	2.83E-01	2.16E-01	2.69E-01	2.06E-01	2.56E-01
L	km	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05
mb	kg	2.06E+02	5.40E+02	1.91E+02	5.02E+02	1.91E+02	5.02E+02
BC	kWh	2.35E+01	8.47E+01	/	/	/	/
Lb	km	1.00E+05	1.00E+05	1.00E+05	1.00E+05	1.00E+05	1.00E+05

2.3.4. HEVs

Differentiated by period of time (t1, t2 and t3) and type (with and without Plug-in): nPHEV_t1, nPHEV_t2 and nPHEV_t3, and PHEV_t1, PHEV_t2 and PHEV_t3.

BASE MODEL (nPHEV_t1 and PHEV_t1): average EURO 5 models. The PHEV is a model with 40 miles autonomy. The nPHEV have a Nickel battery [15].
This defines the following variables: $m_{HEV\ t1}$, $FC_{HEV\ t1}$, $mb_{HEV\ t1}$, and $m_{PHEV\ t1}$, $FC_{PHEV\ t1}$, $mb_{PHEV\ t1}$.

Proportion of PHEV among the HEV:
P_{PHEV} = 50 [%]
Since no data is available about the proportion of nPHEV and PHEV, the proportion is supposed to stay constant at 50/50.

Table S17: Characteristics of the time-differentiated HEV models.

Parameter	*Unit*	*Value*					
		2016-2020		*2021-2025*		*2026-2030*	
		HEV	*PHEV*	*HEV*	*PHEV*	*HEV*	*PHEV*
P	%	*50%*	*50%*	*50%*	*50%*	*50%*	*50%*
m	kg	1.50E+03	1.73E+03	1.41E+03	1.63E+03	1.33E+03	1.54E+03
m_glider	kg	9.97E+02	1.04E+03	9.39E+02	9.85E+02	8.82E+02	9.20E+02
m_PE	kg	9.50E+01	9.96E+01	8.94E+01	9.39E+01	8.41E+01	8.77E+01
m_glider+PE	kg	1.09E+03	1.14E+03	1.03E+03	1.08E+03	9.66E+02	1.01E+03
FC	L/km	4.60E-02	1.40E-02	4.05E-02	1.23E-02	3.57E-02	1.09E-02
FC_real	L/km	5.57E-02	1.69E-02	4.90E-02	1.49E-02	4.32E-02	1.32E-02
EC	kWh/km	/	1.50E-01	/	1.41E-01	/	1.32E-01
EC_real	kWh/km	/	1.73E-01	/	1.62E-01	/	1.52E-01
L	km	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05
m_ICE	kg	3.72E+02	3.90E+02	3.51E+02	3.68E+02	3.30E+02	3.44E+02
mb	kg	3.60E+01	1.97E+02	3.34E+01	1.83E+02	3.34E+01	1.83E+02
Lb	km	1.00E+05	1.00E+05	1.00E+05	1.00E+05	1.00E+05	1.00E+05

2.3.5. REEVs

Differentiated by period of time: REEV_t1, REEV_t2 and REEV_t3.

Ratio of electric range from the total range for a REEV: Rel = 0,1 [%] [16]

Factor of fuel efficiency difference between an ICE used as a motor and as an electricity generator: $F_{FC\ REEV} = 5$ [16]

BASE MODEL (REEV_t1): S-M BEV.

A REEV has the same internal structure than a BEV (glider, electrical powertrain and battery), but with an additional internal combustion engine. Thus, to obtain a vehicle with equivalent comfort of driving (power and size of the glider) for the average REEV than for the small-medium BEV, it has been chosen to take the same glider and electrical powertrain, but with a smaller battery and an additional ICE. This leads to a heavier vehicle.

$m_{\{glider\}\ REEV\ t1} = m_{\{glider\}\ BEV\ SM\ t1}$

$m_{\{electrical\ powertrain\}\ REEV\ t1} = m_{\{electrical\ powertrain\}\ BEV\ SM\ t1}$

$M_{REEV\ T1} = M_{\{glider + electrical\ powertrain\}\ REEV\ t1} + Mb_{REEV\ t1} + M_{\{ICE\}\ REEV\ t1}$

The weight of the internal combustion engine needed is calculated thanks to the proportion mass Glider/mass ICE used in SimaPro, and the mass of the battery is deduced from the average battery capacity from Tate (2008).

Mass of ICE compared to the mass of the glider: $P_{glider/ICE} = 2{,}67647059$ [%] (Ecoinvent v3.1)

$m_{\{glider\}\ REEV\ t1} = P_{glider/ICE} * M_{\{ICE\}\ REEV\ t1}$

Fuel consumption:

Fuel consumption on electric mode: $FC\_el_{REEV\ t1}$ [kWh/km]

$FC\_100el_{REEV\ t1} = FC_{BEV\ SM\ t1}$

Fraction of fuel consumption on electric mode: $FC\_el_{REEV\ t1}$ [kWh/km]

$FC\_el_{REEV\ t1} = FC\_100el_{REEV\ t1} * Rel$

Fraction of fuel consumption on ICE mode: $FC\_ICE_{REEV\ t1}$ [L/km]

Hypothetical fuel consumption of the REEV if the ICE was used as a principal motor: $FC\_hyp_{REEV\ t1}$ [L/km]

Fuel consumption is linked to multiple parameters, the main important ones being the mass of the car, the aerodynamic coefficient of the vehicle and the size of the engine [17]

The mass and the aerodynamic profile of the REEV are comparable to the ones of the ICEV, and the power of their ICE is equal.

$FC\_hyp_{REEV\ t1} = FC_{ICEV\ t1}$

$FC\_ICE_{REEV\ t1} = FC\_hyp_{REEV\ t1} / F_{FC\ REEV} = FC_{ICEV\ t1} / F_{FC\ REEV}$

Table S18: Characteristics of the time-differentiated REEV models.

Parameters	*Unit*	*Value*		
		2016-2020	*2020-2025*	*2025-2030*
m	kg	1.62E+03	1.53E+03	1.44E+03
m_glider	kg	1.06E+03	9.98E+02	9.30E+02
m_PE	kg	1.01E+02	9.51E+01	8.86E+01
m_glider+PE	kg	1.16E+03	1.09E+03	1.02E+03
FC	L/km	1.18E-02	1.04E-02	9.16E-03
FC_real	L/km	1.43E-02	1.26E-02	1.11E-02
EC	kWh/km	1.67E-02	1.57E-02	1.47E-02
EC_real	kWh/km	1.92E-02	1.80E-02	1.69E-02
L	km	1.50E+05	1.50E+05	1.50E+05
m_ICE	kg	3.95E+02	3.73E+02	3.47E+02

mb	kg	7.02E+01	6.52E+01	6.52E+01
BC	kWh	8.00E+00	/	/
Lb	km	1.00E+05	1.00E+05	1.00E+05

2.3.6. FCEVs
Only one average model is defined over the whole period of time.

BASE MODEL (FCEV): S-M BEV t3.
This defines the following variables: m_{FCEV}, and EM_P_{FCEV}.

Fuel consumption:
Hydrogen Low Heating Value: LHV_{H2} = 33.3 [kWh/kg][18]
Fuel cell efficiency: η_{FC} = 0,5 [unitless][19]

$$FC_{FCEV}=FC_{BEV\ SM\ t1} / LHV_{H2} / \eta_{FC}$$

Fuel cells:
The fuel cell inventory is defined per kW. The average fuel cell power needed is then used from the same source [2].

Table S19: Characteristics of the FCEV model.

Parameters	*Unit*	*Value*
m	kg	1210
FC	kg H2 /km	9.00E-03
L	km	1.50E+05
fc	kW	4.00E+01

2.3.7. Models in SimaPro
Whenever a process takes the weight of the car with a workload, a weight of 97.2 kg is the average load of the vehicle (Ecoinvent v3.1)
Emissions from a medium vehicle responding to the EURO 5 norms are used.

In all cases, when vehicles use liquid fuel, the share petrol/diesel is assumed to be 70%/30%. Because petrol cars have an internal combustion engine representing 26% of their weight and the diesel car have an internal combustion engine representing 30% of their weight, an ICE representing 27% (=26%*70%+30%*30%) of the weight of the average vehicle has been chosen.

2.4. Infrastructures

Three types of chargers are implemented in the model:
- Home chargers (HC)
- Public normal chargers (NC)
- Public fast chargers (FC)

Total number of passenger vehicles today in Zone Z: $N_{TOTV\ 0}$ = 422083 [vehicles] [5]

Average number of passenger vehicles per capita in Zone Z today:

$$A_0 = N_{TOTV\ 0} / P_0 = 0,331 \text{ [vehicles/capita]}$$

2.4.1. Home chargers
Usually, the user charges its vehicle mainly during night, trying to avoid to charge outside its home. Therefore, the assumption is made that 100% of the owners of one of these three technologies will install a home charger if they have the possibility to do it, meaning if the type of accommodation they are living in allows them to. Thus the assumption is made that only occupants of individual houses will install a home charger.

Individual and shared houses have a capability to install a charger in their private parking spot or garage. On the contrary, multi-dwelling houses might not have this option, except in few cases. Unfortunately, no statistics about the proportion of multi-dwelling houses with their own parking lot is available, so the assumption is made that occupants of multi-dwelling houses are not able to install a charger.

Proportion of the population living in an individual house in Zone Z: $IH_Z = 31$ [%] [5]

Number of house chargers in use in zone Z in the year Y in scenario S:

$$HC_{Z\,Y\,S} = [(N_{BEV\,Y\,S} - N_{BEV\,2015\,S}) + P_{PHEV}*(N_{HEV\,Y\,S} - N_{HEV\,2015\,S}) + (N_{REEV\,Y\,S} - N_{REEV\,2015\,S})]*\ IH_Z$$

Table S20: Number of home chargers to implement per year per scenario

	B10	**B100**	**BEV++**	**FCEV++**
HC_2016_Z	868	868	603	603
HC_2017_Z	4869	1633	4869	3184
HC_2018_Z	10404	3711	11770	10404
HC_2019_Z	18143	6528	20908	25748
HC_2020_Z	25354	8708	31648	44937
HC_2021_Z	32012	11641	44743	65255
HC_2022_Z	39879	15208	58829	78136
HC_2023_Z	48620	18989	71023	85478
HC_2024_Z	56058	23204	85627	86723
HC_2025_Z	64353	28228	99004	87208
HC_2026_Z	72027	32961	111094	87654
HC_2027_Z	78298	37010	122589	85054
HC_2028_Z	85010	41108	128156	80469
HC_2029_Z	91021	44485	134505	76526
HC_2030_Z	96304	48658	136265	73250

2.4.2. Normal Chargers

General considerations

Methods found in the literature:

[20,21] have used two different techniques of calculations in two articles focusing on charging infrastructures. The first one was based on the average service ratio (chargers/cars) needed in 2020, which had been calculated by a Portuguese charger infrastructure implementer. Despite its simple applicability, the results of this technique are limited to Portugal. In their following paper, Lucas et al. used a service ratio formula, based on the yearly driven distance per vehicle. More precise than the first one, this technique permits a better adaptation to the specific frame of the study. On a more factual way, a Danish research team [22] studied the situation of Denmark in case of relative deployment of BEVs in the whole country. The driving range and the geographical applicability are well-defined and precise, increasing the level of reliability as compared to the previous methods. Another and more technical approach consists of assessing the area under study to identify the peak consumption of an average day [23]. The number of chargers needed is then simply deduced from the energy required to satisfy the peak, and represents the optimal number needed in the area to answer the demand. Nevertheless, finding the peak consumption is highly challenging and requires a complex and detailed study of the transportation trends of the area under study. Furthermore, this implies that 100% of the chargers need to be used to answer the demand at peak hour, which may be difficult in reality. Another "top-need approach" has been developed by [24], but instead of using at the theoretical peak energy needed, it establishes the average parking patterns, and assumes that users will chose to charge their car every time they have the

possibility to do it, in other words every time they are parked [24]. This technique does not give a theoretical optimal number of chargers needed, because of the extreme nature of the underlying assumption.

New method developed in this study:
First, BEV owners who do not have the possibility to install a charger at home will need public chargers for their primary charge. One public charger for two cars would be sufficient for a comfortable use of the cars (Dansk Energi, personal communication, February 1st, 2016). On the contrary, because of the short time of charge, REEV and PHEV will not require the installation of extra public chargers. As the market share for electric vehicles grows, companies, as well as public and private institutions will gradually install normal chargers in their parking lots to meet the increasing demand of their employees, customers and users. It can easily be imagined that shops which add charging stations for their customers' vehicles will be preferred by most BEV, REEV and PHEV owners. This would encourage the installation of charging stations in all the main parking lots of the city. Companies would potentially be willing to increase the convenience to their employees. This could potentially lead to a much higher number of charging stations installed than the optimal needed to meet demand.

Table S21: Summary of the different methods found to determine how many normal charging infrastructures should be installed with their source, their advantages and their disadvantages.

Method	Source	Advantages	Disadvantages	Used here
Average service ratio	20	Extremely easy to apply.	Specifically adapted to Portugal. Simplistic.	No
Service ratio formula	21	Depends on km travelled per year.	Specifically adapted to Portugal.	No
Danish need per location	22	Specifically adapted to Denmark. Well-defined frame.	Cannot be adapted for different driving habits.	Yes (m1)
Peak consumption	23	Accurate, technically speaking.	Extremely hard to find the actual peak energy needed in an area. 100% of the chargers used at peak hour.	No
Parking time	24	Extremely easy to apply.	Overestimate compared to optimum.	Yes (m2)
Need per location	/	Based on the actual state of the area under study. Marketing based.	Overestimate compared to optimum.	Yes (m3)

Methods used in this study

Method 1: Extrapolation of the Danish report EDISON
Denmark is differentiated in different categories of areas:

- Copenhagen and Frederiksberg municipalities
- Aalborg, Odense and Aarhus
- Cities with 35-100,000 inhabitants
- Cities with 20-35,000 inhabitants
- Cities with 10-20,000 inhabitants
- Cities with 5-10,000 inhabitants

DATA:
Number of public charging stations needed if 100000 BEVs are bought in Denmark in dense areas due to night charging in category C: $NC_{night\ C}$

Number of public charging stations needed if 100000 BEVs are bought in Denmark in work places, supermarkets, etc, due to day charging in category C: $NC_{day\ C}$

Table S22: Number of public NC to implement in the different zones for night and day use [22]**.**

CATEGORY C	NC_	
	night_C	day_C
Copenhagen and Frederiksberg municipalities	4 393,00	654,00
3 cities (Aalborg, Odense and Arhus)	1 484,00	404,00
Cities with 35-100,000 inhabitants	1 126,00	525,00
Cities with 20-35,000 inhabitants	634,00	242,00
Cities with 10-20,000 inhabitants	738,00	294,00
Cities with 5-10,000 inhabitant	642,00	287,00
Total	9 017,00	2 406,00

Number of cities belonging to area type A in Denmark: $NP_{DK\ A}$
Number of cities belonging to area category C in Zone Z: $NP_{Z\ A}$

Table S23: Number of cities in the different categories in Zone Z [5]

CATEGORY C	NP_DK_C	NP_Z_C
Copenhagen and Frederiksberg municipalities	2	2
3 cities (Aalborg, Odense and Arhus)	3	0
Cities with 35-100,000 inhabitants	56	8
Cities with 20-35,000 inhabitants	19	3
Cities with 10-20,000 inhabitants	3	2
Cities with 5-10,000 inhabitant	6	0

Population today in Denmark: P_{DK} = 5 707 251 [capita] [5]

CALCULATIONS:
Percentage of the population of Denmark living in Zone Z:
$\%pop_{Zone\ Z} = P_0 / P_{DK} = 22$ [%]
The hypothesis is made that the number of vehicles bought is proportional to the population.
Number of electric vehicles bought in zone Z if 100 000 BEVs are bought in Denmark:

$$NBEV_{100\ 000\ Z} = 100\ 000 * \%pop_Z = 22\ 345$$

Percentage of cities belonging to category C in zone Z:

$$\%C_Z = NP_{Z\ A} / NP_{DK\ A}\ [\%]$$

Number of public charging stations needed if 100000 BEVs are bought in Denmark (corresponding to $NBEV_{100\ 000\ Z}$ bought in Zone Z) in dense areas due to day and night charging in category C in Zone Z:
$NC_{A\ Z} = (NC_{night\ C} + NC_{day\ C}) * \%C_Z$
Total number of public charging station needed in Zone Z if 100000 BEVs are bought in Denmark:

$$NC_{TOT\ Z} = \sum_A NC_{A_Z}$$

Number of public normal charging station that need to be in use in year Y in scenario S in Zone Z (method 1):

$$NC_{Y\ S\ Z\ m1} = (N_{BEV\ Y\ B10} - N_{BEV\ 2015\ B10})*NBEV_{100000\ Z} * CS_{TOT\ Z}$$

Table S24: Number of normal chargers to implement with method 1 per year per scenario

	B10	**B100**	**BEV++**	**FCEV++**
NC_2016_Z_m1	355	355	355	355
NC_2017_Z_m1	842	367	842	1437
NC_2018_Z_m1	2062	376	3267	3267
NC_2019_Z_m1	3921	385	5750	8188
NC_2020_Z_m1	5204	393	9521	14455
NC_2021_Z_m1	5890	402	14622	18364
NC_2022_Z_m1	7220	914	19831	21092
NC_2023_Z_m1	8575	1565	24506	22595
NC_2024_Z_m1	9954	2228	30555	23473
NC_2025_Z_m1	11355	3554	38659	23707
NC_2026_Z_m1	14088	4246	45584	24587
NC_2027_Z_m1	16864	4949	51284	24807
NC_2028_Z_m1	21012	5660	57054	25684
NC_2029_Z_m1	25215	5707	62886	26561
NC_2030_Z_m1	29469	6430	66060	28114

Method 2: EPRI

The very maximum number of chargers needed happens if all the vehicles want to charge every time they are plugged in and during the entire time they are plugged in.

Maximum average percentage of vehicles parked in the working place: $P_{max\ workingplace} = 27$ [%] [24]

Maximum average percentage of vehicles parked in the public space: $P_{max\ public} = 15$ [%] [24]

Number of public normal charging station that need to be in use in the year Y in scenario S in Zone Z (method 2):

$$NC_{Y\ S\ Z\ m2} = (N_{BEV\ Y\ S} - N_{BEV\ 2015\ S}) * (P_{max\ workingplace} + P_{max\ public})$$

Table S25: Number of normal chargers to implement with method 2 per year per scenario

	B10	**B100**	**BEV++**	**FCEV++**
NC_2016_Z_m2	546	546	546	546
NC_2017_Z_m2	1294	564	1294	2208
NC_2018_Z_m2	3169	578	5020	5020
NC_2019_Z_m2	6024	592	8835	12581
NC_2020_Z_m2	7996	605	14629	22210
NC_2021_Z_m2	9051	617	22466	28216
NC_2022_Z_m2	11094	1405	30471	32408
NC_2023_Z_m2	13176	2405	37654	34717
NC_2024_Z_m2	15294	3424	46948	36067
NC_2025_Z_m2	17447	5461	59399	36425
NC_2026_Z_m2	21647	6525	70039	37778
NC_2027_Z_m2	25911	7604	78798	38116
NC_2028_Z_m2	32284	8697	87664	39464
NC_2029_Z_m2	38743	8770	96623	40810
NC_2030_Z_m2	45279	9879	101501	43197

Method 3: Need per location
There are two types of charging: primary charging, which happens mainly at night and at home, and secondary charging, which happens anywhere the driver is, with the only purpose to finish its trip.

- Primary charging: If the people who do not a private parking spot want to be able to have an electric car, a certain number of public chargers are needed.
- Secondary charging: depends entirely on the driving range, which keeps evolving, and less and less vehicles need to charge again during the day. However, multiple places will take the decision to build a charger in their parking lot. Among others, the companies, and especially the ones with many employees.

DATA:
Number of vehicles per charger needed for primary charging: $N_{primary\ public} = 2$ [22]
Number of workplaces with 20 to 49 employees in zone Z: $N_{workplaces\ 20\ Z} = 3916$ [5]
Number of workplaces with 50 to 99 employees in zone Z: $N_{workplaces\ 50\ Z} = 1198$ [5]
Number of workplaces with more than 100 employees in zone Z: $N_{workplaces\ 100\ Z} = 783$ [5]
Number of chargers needed per workplaces with 20 to 49 employees: $N_{NC\ 20} = 1$
Number of chargers needed per workplaces with 50 to 99 employees: $N_{NC\ 50} = 2$
Number of chargers needed per workplaces with more than 100 employees: $N_{NC\ 100} = 4$
Percentage of workplaces of size X that have installed normal chargers in year Y in high-BEV deployment scenarios (B10, BEV++ and FCEV++) in 2030:
$P_{workplaces\ X\ S}$ [%]

Table S26: Percentage of workplaces of size X that have installed normal chargers in year Y in high-BEV deployment scenarios (B10, BEV++ and S4) in 2030

Size of the company	**P_workplaces**	
	B10	B100
	2030	2030
Less than 20	0,5	0,25
From 20 to 50	0,6	0,3
More than 50	0,9	0,45

Number of chargers needed in other public places before 2030 (shops, schools, churches, streets, etc) in high-BEV deployment scenarios (B10, BEV++ and FCEV++): $N_{NC\ other\ S} = 500$

CALCULATIONS:
When it comes to public chargers, the assumption is made that twice less infrastructures will be built in scenario B100 than in high- BEV deployment scenarios.
Percentage of workplaces of size X that have installed normal chargers in year Y in scenario B100:
$P_{workplaces\ X\ B100} = P_{workplaces\ X\ B10} / 2$ [%]
Number of chargers needed in other public places before 2030 (shops, schools, churches, streets, etc) in scenario B100:
$N_{NC\ other\ B100} = N_{NC\ other\ B10} / 2$

The number of public chargers that are not at workplaces are equally distributed among the time-scope.
Number of normal chargers needed to be in use in scenario S in zone Z in year Y:

$$NC_{Y\ S\ Z\ m3} = (N_{BEV\ Y\ S} - N_{BEV\ 2015\ S}) * \frac{1 - IH_Z}{N_{primary_{public}}} + (N_{workplaces\ 20\ Z} * N_{NC\ 20} * P_{workplaces\ S\ 20} + N_{workplaces\ 50\ Z} * N_{NC\ 50} * P_{workplaces\ S\ 50} + N_{workplaces\ 100\ Z} * N_{NC\ 100} * P_{workplaces\ S\ 100} + N_{NC\ other\ S})\ (Y-2015)/15$$

Table S27: Number of normal chargers to implement with method 2 per year per scenario

	B10	B100	BEV++	FCEV++
NC_2016_Z_m3	896	672	896	896
NC_2017_Z_m3	1958	910	1958	2709
NC_2018_Z_m3	3946	1146	5466	5466
NC_2019_Z_m3	6739	1381	9047	12125
NC_2020_Z_m3	8806	1616	14255	20482
NC_2021_Z_m3	10120	1850	21140	25863
NC_2022_Z_m3	12246	2721	28163	29754
NC_2023_Z_m3	14404	3766	34511	32098
NC_2024_Z_m3	16592	4827	42593	33655
NC_2025_Z_m3	18807	6724	53268	34397
NC_2026_Z_m3	22705	7821	62456	35955
NC_2027_Z_m3	26655	8932	70099	36681
NC_2028_Z_m3	32338	10054	77828	38236
NC_2029_Z_m3	38091	10337	85636	39790
NC_2030_Z_m3	43908	11472	90090	42197

2.4.3. Fast chargers

Fast public chargers are not essential, but substantially increase the convenience of owning a BEVs since it allows the owner to drive a bigger distance than the driving range in one travel. Indeed, because of the long time needed to charge entirely a BEV with a normal charger (from 6 to 8 h in average), trips of longer distance than the autonomy of the vehicle are not feasible without the possibility of fast charging**.** [24] concludes that 5 fast chargers per 1000 EVs are enough to drastically increase the proportion of long trips possible with a BEV.

With the driving range that will increase, the need of fast charge will reduce. With a range of 120km, it is already less than 4%. The locations of the fast charging facilities will then depend more on where do people that want to fast charge need the fast chargers the most. Since the need of fast charging is related to the need of doing long trips, it is likely that these locations happen to be along the highways. Then, the Danish government will decide to implement a certain amount of fast chargers in total.

DATA:

Number of fast charger needed per 1000 vehicles: $FCh_{1000} = 5$ [24]

CALCULATIONS:

Number of fast chargers needed in use in year Y in zone Z in scenario S:

$$FCh_{Y\ Z\ S} = (N_{BEV\ Y\ S} - N_{BEV\ 2015\ S}) * FCh_{1000} / 1000$$

Table S28: Number of fast chargers to implement per year per scenario

	B10	B100	BEV++	FCEV++
FCh_2016_Z	6	6	6	6
FCh_2017_Z	15	6	15	26
FCh_2018_Z	37	6	59	59
FCh_2019_Z	71	7	105	149
FCh_2020_Z	95	7	174	264
FCh_2021_Z	107	7	267	335
FCh_2022_Z	132	16	362	385
FCh_2023_Z	156	28	448	413

FCh_2024_Z	182	40	558	429
FCh_2025_Z	207	65	707	433
FCh_2026_Z	257	77	833	449
FCh_2027_Z	308	90	938	453
FCh_2028_Z	384	103	1043	469
FCh_2029_Z	461	104	1150	485
FCh_2030_Z	539	117	1208	514

2.5. Electricity portfolio

The marginal Danish electricity mix in Ecoinvent v.3.1 is taken as basis (Table S29). Then goals determined by the EU and the Danish government are used as the hypothetical portfolio for 2020, 2030 and 2050 [25–27]. The yearly mix is thus determined linearly in between. In this report, only the mix between 2015 and 2030 are used.

Table S29: Marginal Danish electricity mix considered for 2015 as a basis to build on.

Energy sources	Marginal mix (%)
Hard coal	56.2
Natural gas	0.0
Oil	0.0
Hydropower	0.1
Wind (on-shore), <1MW	17.5
Wind (on-shore), 1-3MW	6.0
Wind (on-shore), >3MW	3.1
Wind (off-shore), 1-3MW	17.1
Wood pellets	0.0
Wood chips	0.0
Municipal waste	0.0
Biogas	0.0

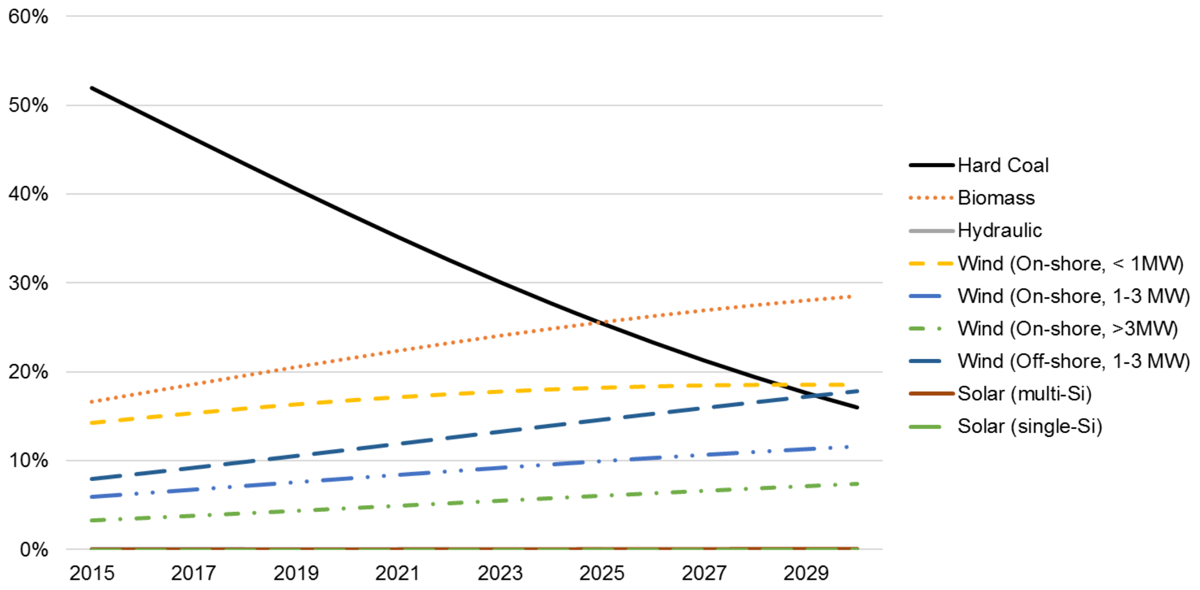

Figure S32: Evolution of the Danish electricity portfolio from 2015 to 2030

3. Sensitivity analysis

The first sensitivity analysis considered how taking the long-term emissions into account or not impacted the results. Depending on the environmental mechanism considered, effects on the environment and human health can occur at different point in time. For instance, landfills' leaches will mainly have consequences in thousands of years from now. These temporal aspects, and if they should be considered with equal weight in the life cycle impact assessment, is a highly debated subject for LCA experts [28]. How these emissions will be treated in the future is totally unknown, so it is complicated to define their actual impacts. Two types of emissions are usually differentiated: short-term and long-term ones with a turning point being generally 100 years. The second and the third sensitivity analysis concerned the choice of the method to quantify the charging infrastructures (see section 2.5.3). The fourth sensitivity parameter to be assessed was the evolution of the ratio of large BEVs compared to small-medium ones until 2030 in the BEV fleet. The data from Dansk Energi show that the proportion of large vehicles among BEV is currently of 45%, a much higher number than the proportion of the same type of vehicles in the global fleet which is only 10%. Therefore, it has been chosen to make it decrease through the years until it reaches 10% of luxury/large cars in 2025. However, this transition is uncertain since it will depend on technologies improvements. Therefore, another set of values have been tested undergoing a slower decrease of the proportion of big vehicles that will reach only 35% in 2025. Another potentially influencing parameter is the fuel consumption reduction rate. Indeed, fuel and electricity consumption usually are responsible of more than half of the final scores in some impact categories like e.g. climate change, according to the existing LCA in that field [1]. Additionally, most of the exhaust emissions from the fuel-powered vehicles are related to the fuel consumption. As well as the evolution of the proportion of large BEV, the future fuel consumption will depend on the technologies' development within the next decades, and is thus hard to anticipate. An average yearly reduction rate of 2,5% for fossil fuels and 1,25% for electricity was adopted for the study, which was increased by 10% for a fifth sensitivity analysis. Finally, a new electricity mix has been considered, in order to simulate a faster penetration of renewable energies until 2030, constituting the last sensitivity analysis. In the predictive scenario of the EU, the Danish mix will be composed in 2030 by approximately 55% of wind energy, 29% of biomass, 16% of coal and very few hydro- and solar power. For the sensitivity analysis, a scenario where 65% of wind and 32% of biomass is reached was tested.

Table S30: Summary of the parameters considered in the sensitivity analysis with their description, their value in the main study and their variation.

No.	Parameter considered	Description	Value or set of values used in the main study	New value or set of values
1	Long-term emissions	The effects occurring in more than 100 years are not considered.	With long-term emissions	Without long-term emissions
2	Infrastructure method	Two other methods to calculate the number of infrastructures to be implemented are tested [a].	m1[a]	m2[a]
3	Infrastructure method		m1[a]	m3[a]
4	Proportion of large BEV VS small-medium BEV	The reduction of the proportion of large BEVs comparing to small and medium ones is slowed down until 2030.	2016-2020: 45% large BEV 2021-2025: 30% large BEV 2026-2030: 10% large BEV	2016-2020: 45% large BEV 2021-2025: 40% large BEV 2026-2030: 35% large BEV
5	Fuel consumption decrease rate	The yearly fuel consumption reduction rate is increased by 10%.	-2,5%/year (fossil fuels) -1,25%/year (electricity)	-2,75%/year (fossil fuels) -1,375%/year (electricity) *(+10%)*
6	Electricity mix	The yearly composition of the electricity mix is changed until 2030 to obtain a mix with more renewables.	Danish mix in 2030: 16% of hard coal 29% bio energy 55% wind energy	Danish mix in 2030: 3% of hard coal 32% bio energy 65% wind energy

[a]: see section S2.4

References for the electronic supplementary information

(1) Bauer, C.; Hofer, J.; Althaus, H.-J.; Del Duce, A.; Simons, A. The environmental performance of current and future passenger vehicles: Life cycle assessment based on a novel scenario analysis framework. *Appl. Energy* **2015**, *157,* 871–883.

(2) Simons, A.; Bauer, C. A life-cycle perspective on automotive fuel cells. *Appl. Energy* **2015**, *157*, 884–896.

(3) Rørbech, J. T.; Vadenbo, C.; Hellweg, S.; Astrup, T. F. Impact assessment of abiotic resources in LCA: Quantitative comparison of selected characterization models. *Environ. Sci. Technol.* **2014**, *48* (19), 11072–11081.

(4) EC. *International Reference Life Cycle Data System (ILCD) Handbook: General guide for Life Cycle Assessment - Detailed guidance*, First Edit.; Publications Office of the European Union: Luxembourg, 2010.

(5) Statistik Banken. Statistik Banken http://www.statistikbanken.dk/ (accessed Apr 14, 2016).

(6) The Danish National Travel Survey. The Danish National Travel Survey http://www.modelcenter.transport.dtu.dk/english/TU (accessed Apr 14, 2016).

(7) McKinsey & Company. *Boost! Transforming the powertrain value chain – a portfolio challenge*; Berlin, DE, 2011.

(8) The International Council on Clean Transportation. *European Vehicle Market Statistics Pocketbook 2015/16*; International Council on Clean Transportation: Berlin, DE, 2015.

(9) Querini, F.; Benetto, E. Combining agent-based modeling and life cycle assessment for the evaluation of mobility policies. *Environ. Sci. Technol.* **2015**, *49* (3), 1744–1751.

(10) Del Duce, A.; Gauch, M.; Althaus, H. J. Electric passenger car transport and passenger car life cycle inventories in ecoinvent version 3. *Int. J. Life Cycle Assess.* **2016**, *21* (9), 1314–1326.

(11) Element Energy. *Influences on the low carbon car market from 2020-2030 - Final report for Low Carbon Vehicle Partnership*; Element Energy Limited: Cambridge, UK, 2011.

(12) Garcia, R.; Gregory, J.; Freire, F. Dynamic fleet-based life-cycle greenhouse gas assessment of the introduction of electric vehicles in the Portuguese light-duty fleet. *Int. J. Life Cycle Assess.* **2015**, *20* (9), 1287–1299.

(13) USABC. *USABC Goals for Advanced Batteries for EVs - CY 2020 Commercialization*; United States Advanced Battery Consortium, 2014.

(14) ACEA. Passenger Car Fleet by Fuel Type. Statistics provided by the European Automobile Manufacturers' Association http://www.acea.be/statistics/tag/category/passenger-car-fleet-by-fuel-type (accessed Apr 14, 2016).

(15) Domingues, A. R.; Marques, P.; Garcia, R.; Freire, F.; Dias, L. C. Applying multi-criteria decision analysis to the life-cycle assessment of vehicles. *J. Clean. Prod.* **2015**, *107*, 749–759.

(16) Tate, E. D.; Harpster, M. O.; Savagian, P. J. The Electrification of the Automobile: From Conventional Hybrid, to Plug-in Hybrids, to Extended-Range Electric Vehicles. *SAE Int. J. Passeng. Cars - Electron. Electr. Syst.* **2008**, *1* (1), 156–166.

(17) Mellios, G.; Hausberger, S.; Keller, M.; Samaras, C.; Ntziachristos, L. *Parameterisation of fuel consumption and CO2 emissions of passenger cars and light commercial vehicles for modelling purposes*; JRC European Commission, Ed.; European Union: Luxembourg, 2011.

(18) US department of energy. Lower and Higher Heating Values of Fuels http://hydrogen.pnl.gov/tools/lower-and-higher-heating-values-fuels.

(19) US Department of Energy. Hydrogen Fuel Cells Fact Sheet. **2006**.

(20) Lucas, A.; Silva, C. A.; Costa Neto, R. Life cycle analysis of energy supply infrastructure for conventional and electric vehicles. *Energy Policy* **2012**, *41*, 537–547.

(21) Lucas, A.; Neto, R. C.; Silva, C. A. Energy supply infrastructure LCA model for electric and hydrogen transportation systems. *Energy* **2013**, *56*, 70–80.

(22) EDISON Consortium. *Report Work Package 1.3 - Electric vehicles and the customers*; EDISON Consortium: Kgs. Lyngby, DK, 2011.

(23) Nègre, L. *Livre Vert sur les infrastructures de recharge ouvertes au public pour les véhicules « décarbonés »*; French government, Ed.; République Française: Paris, FR, 2011.

(24) EPRI. *Guidelines for Infrastructure Planning*; Electric Power Research Institute: Palo Alto, CA, USA, 2014.

(25) The Danish Government. *Energy Strategy 2050 - from coal, oil and gas to green energy*; The Danish Ministry of Climate and Energy: Copenhagen, DK, 2011.

(26) IEA. *Energy Policies of IEA countries - European Union 2014 Review*; International Energy Agency: Paris, FR, 2014.

(27) IEA. *Energy Policies of IEA countries - Denmark 2011 Review*; International Energy Agency: Paris, FR, 2011.

(28) Hellweg, S.; Milà i Canals, L. Emerging approaches, challenges and opportunities in life cycle assessment. *Science.* **2014**, *344* (6188), 1109–1113.