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Influence of the uptake of electric vehicles on the impact on climate change of an entire future vehicle fleet, a 2020 Brussels perspective

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Abstract

Electric vehicles have a clear benefit over conventional vehicles when it comes to the impact on climate change. Underlying paper describes how fast (or slow) the uptake of electric vehicles can change the overall performance of an entire fleet on climate change. The benefit of a large share of electric vehicles in a fleet is compared to a future fleet with energy efficient conventional vehicles (petrol and diesel). The study area is the car fleet of Brussels, Belgium. The time horizon is 2020. It is investigated how big the climate benefits can be of a potential uptake of electric vehicles in a fleet. Two different vehicle fleets of the Brussels Capital Region (BCR) are compared with a Life Cycle Assessment (LCA), consisting of a 'business as usual' and an 'EV uptake' set of vehicles. Future electricity mixes, with more renewable energy, are taken into account. It is concluded that a moderate uptake of electric vehicles (as described in the paper) leads to a yearly emission reduction of 10 kton CO_2 in 2020 for the Brussels Fleet compared to a reference scenario. This means that in 2020 it is possible to have a fleet in Brussels consisting of 1,8% BEV's 1,6% PHEV's that reduces 1,9% (or 10 kton CO_2) of the yearly CO_2 emissions when compared to a 'Business as usual' scenario.

Keywords: Life Cycle Assessment, Fleet assessment, Sustainability, climate change, electric vehicles

1 Introduction

Transport plays an important role in the overall anthropogenic impact on climate change. Figure 1 shows the top 5 sectors contributing to CO_2 emissions in EU-27, 23% of all CO_2 emissions in EU-27 are due to transportation. Road transport is by far (71%) the largest contributor of the CO_2 emissions from transportation [1], see Figure 1.

The main important greenhouse gases are CO_2, CH_4 and N_2O. All conventional vehicles burn hydrocarbon fuels derived from fossil energy sources, in their engines to create the necessary speed and torque. Most of the CO_2 emissions coming from conventional vehicles are emitted in the tailpipe emissions [2]. Carbon dioxide (CO_2) is created by burning the hydrocarbon fuels. Thus, the emission levels of CO_2 are directly related to fuel consumption. Fuel saving technologies, such as battery electric vehicles (BEV) and plug-in

electric vehicles (PHEV) will directly decrease CO_2 emissions.
The goal of this paper is to identify and describe the impact of the inclusion of these efficient electric vehicles in a vehicle fleet on the overall transport related greenhouse gases.

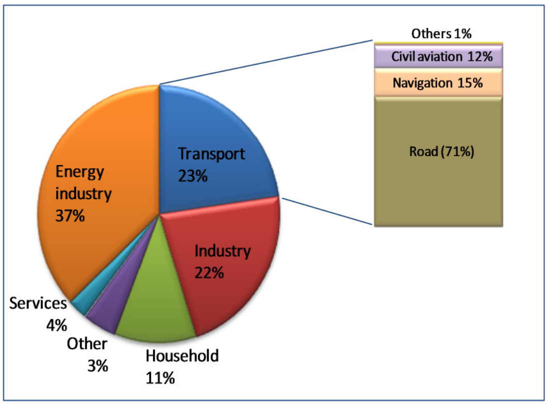

Figure 1: Contribution of different sectors in EU-27 to the exhaust of CO_2 emissions [1].

To calculate the effect on climate change, a full Life Cycle Assessment (LCA) approach is taken into account. Furthermore, it is investigated how fast an uptake of electric vehicles in a fleet can change the overall performance of a fleet on climate change. Over the coming years new conventional vehicles will improve the fuel efficiency, influencing the relative greenhouse benefit of electric vehicles. The study area is the car fleet of Brussels, Belgium. The time horizon is 2020. It is investigated how large the climate benefits can be of a potential uptake of electric vehicles in a fleet. Future electricity mixes, with more renewable energy, are taken into account. How fast will an uptake of electric vehicles change the impact of an entire fleet on climate change? The benefit of a large electric vehicle share in a fleet needs to be compared to a future fleet with conventional vehicles that will be more and more energy efficient.

2 Benefits of electric vehicles

The aim of the paper is to compare two different vehicle fleets in the period 2010-2020 using the Life Cycle Assessment (LCA) methodology. The two different vehicle fleets of the Brussels Capital Region (BCR) that are compared consist of a 'business as usual' and an 'EV uptake' set of vehicles. Comparing entire vehicle fleets with LCA is challenging, so first the LCA impact on climate change of individual vehicles will be investigated in this paragraph. In order to create a methodological framework for the practice of LCA on the one hand and to ensure that all requirements of the methodologies are met on the other hand, the International Standardization Organization (ISO) has published two standards, namely the ISO 14040 [3] and the ISO 14044 [4].
In the 'Clean Vehicle Research: LCA and policy measures' (CLEVER) project, an extensive LCA has been performed of the complete Belgian passenger car fleet. The effect on climate change of vehicles with conventional (diesel, petrol) and alternative fuels (such as liquefied petroleum gas (LPG) and compressed natural gas (CNG)) and drive trains (combustion engines and battery and hybrid electric vehicles) has been analysed in a Belgian context [5]. This LCA model will be used to calculate an LCA of a whole fleet.
The different vehicles are mutually compared on the same basis, defined as the functional unit (FU), to ensure an objective comparison. The FU of this LCA has been defined as the use of a passenger car in Belgium over a lifetime driven distance of 230.500 km corresponding to a vehicle lifespan of 13,7 years [6,7]. The methodology, assumptions, inventory and model can be found in [8], [9]. The life cycle inventory includes greenhouse gases from the extraction of raw materials, the manufacturing of components, the assembly, the use phase (on a well-to-wheel (WTW) basis) and the end-of-life (EOL) treatment. It is clear that a battery electric vehicle (BEV), powered with electricity from the Belgian grid, has a lower impact on climate change than all other vehicle technologies (including petrol, diesel, liquefied petroleum gas (LPG), compressed natural gas (CNG) and hybrid vehicles). In order to make a fair comparison, equivalent vehicles with different technologies were chosen for the LCA. In Table 1 equivalent vehicles are listed and some emissions are compared together with fuel consumption. These vehicles are a compact size and follow the newest European Emission standards (Euro 5). The vehicle specifications were measured on the NEDC (New European Driving Cycle) driving cycle.

Table 1: Tank-to-Wheel emissions of different vehicle technologies [g/km] and fuel consumption

Fuel	CO_2	CO	HC	NO_x	PM	Fuel consumption
Petrol, VW Golf	134	0,24	0,023	0,021	0	5,8 l/100km
Diesel, VW Golf	99	0,37	0,038	0,130	0,001	3,8 l/100km
LPG, VW Golf	169	0,33	0,032	0,012	0	7,1 l/100km

CNG, Fiat Punto	115	0,53	0,042	0,022	0	6,3 l/100km
Hybrid, Toyota Auris	93	0,17	0,034	0,006	0	4 l/100km
BEV, Nissan Leaf	0	0	0	0	0	15 kWh/100 km

In Table 1 the tailpipe emissions are shown of the different vehicle technologies. The emissions are compared in Figure 2 with the petrol vehicle as a reference.

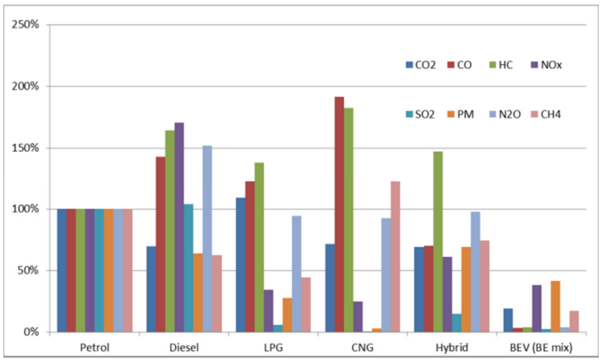

Figure 2: Comparison of the NEDC tailpipe emissions from different vehicle technologies, with petrol as a benchmark

In Figure 3 a life cycle climate change impact is shown for different vehicle technologies. For comparison reasons the result shows only individual vehicles, later on in the paper LCA results of a whole fleet will be shown. The climate change impact is expressed in g CO_2eq/km, taking into account all the life phases of a vehicle and its lifetime mileage. The BEV using the Belgian supply mix electricity has the lowest climate change impact. This good score of the BEV can be explained by the fact that 55% of the Belgian production mix electricity is nuclear and the fact that BEV is an exhaust emission free vehicle. The contribution of the lithium ion battery manufacturing process to the overall impact is important. However, a large share of the impact of the lithium battery is balanced by the benefit of the recycling. Negative impacts on the graph are induced by credits from recycling.

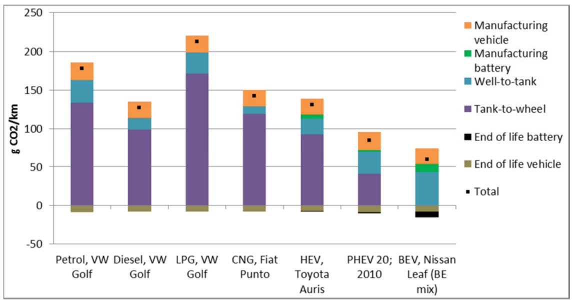

Figure 3: Comparative life cycle CO_2 emissions of different vehicle technologies

In order to calculate the life cycle greenhouse gas emissions of the 'EV-uptake' scenario, the future electricity mixes of Belgium must be taken into account. A growing share of renewable energy is expected to be implemented in the 2010-2020 period. In the year 2010 following electricity mix was taken into account: 10% coal, 2% oil, 27% natural gas, 2% hydro, 55% nuclear, 3% biomass and 1% wind. In 2020 it is expected that 20,3% of the electricity will be produced with renewable energy, see Figure 4 [10]. The environmental performance of a BEV is influenced by the type of electricity production. Figure 5 shows the life cycle climate change impact of a BEV and a plug-in hybrid electric vehicle (PHEV) in 2010 and 2020. The renewable energy share of the electricity mix of Belgium increases in 2020 to 20,3%, lowering the Well-to-tank induced environmental impact. For the PHEV it is assumed that the electric range will increase throughout the years, from 20 km in 2010 (PHEV 20) to 60 km in 2020 (PHEV 60).

Figure 4: Share of renewable energy production in the Belgian electricity mix

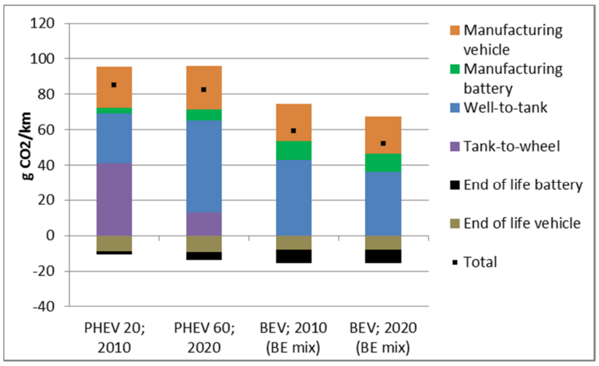

Figure 5: Life Cycle Climate change impact of PHEV and BEV in 2010 and 2020 [g CO_2/km]

3 Evolution of the Brussels car fleet in the 'business as usual' scenario

To obtain a correct image of the benefit of the uptake of electric vehicles, the evolution of a fleet over different years should be followed. Therefore, projections are made of the composition of the private vehicle fleet in the Brussels Capital Region (BCR). Two scenarios are examined. In the first 'business as usual' scenario it is considered that no extra electric vehicles will be part of the fleet. The future technological improvements of conventional vehicles are taken into consideration. The second scenario considers an uptake of electric vehicles and is called the 'EV-uptake' scenario. Both projections are made with 2020 as time horizon. In the 'business as usual' scenario, the effects on the supply side (technological improvements) are considered. Effects on the demand side like the effect of a future tax reform on car purchases of consumers are not included.

3.1 The fleet of vehicle registrations of new cars

Since there is no growing trend observed in the Brussels Capital Region in the new number of cars registered every year, the same amount of private passenger cars (19.597) as in 2010 is taken into account for all years (2011-2020). The roads of the Brussels Capital Region are already saturated. As a result of the developments of direct ignition petrol cars by manufacturers, suggestions of the Federal State to reduce the difference between the fuel excises on diesel and petrol and the recent scrappage of the Federal State subsidies for the purchase of a low CO_2-emitting car, it has been assumed that diesel cars will lose an annual market share of 10% in favour of petrol cars. Table 2 gives an overview of the technology split (amount of Diesel, Petrol, LPG, CNG and EV cars) as a result of this assumption.

Table 2: Technology split of new vehicles in the 'Business as usual' scenario (in # cars)

	Petrol	CNG	Diesel	BEV	LPG	Total
2010	8167	0	11426	0	4	19597
2011	9310	0	10283	0	4	19597
2012	10338	0	9255	0	4	19597
2013	11263	0	8330	0	4	19597
2014	12096	0	7497	0	4	19597
2015	12846	0	6747	0	4	19597
2016	13521	0	6072	0	4	19597
2017	14128	0	5465	0	4	19597
2018	14674	0	4919	0	4	19597
2019	15166	0	4427	0	4	19597
2020	15609	0	3984	0	4	19597

The average tailpipe CO_2 emissions for the new vehicle fleet will further reduce in the coming years. This assumption can be sustained by the fact that more and more petrol and diesel vehicles will get some sort of hybridization (start-stop, mild, strong, plug-in), which will consequently lead to an important drop in CO_2 emissions. Based on these technical projections of the private vehicle fleet, the impact on CO_2 emission can be calculated for the period 2010-2020. The average CO_2 emissions per kilometre per vehicle of the new car fleet are decreasing over the years. The average CO_2/km will decrease from 136 g CO_2/km (petrol) and 126 g CO_2/km (diesel) in 2010 to 102 g CO_2/km (petrol) and 104 g CO_2/km (diesel) in 2020. This positive trend induces a decrease of the yearly tailpipe emissions from new vehicles, as shown in Figure 6.

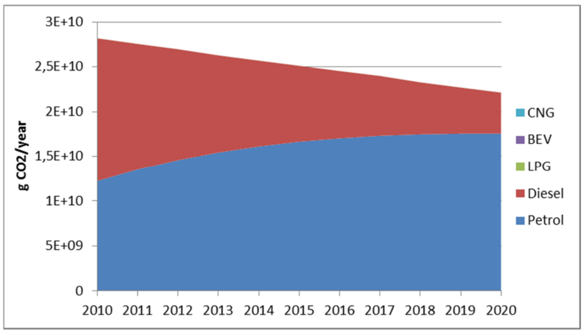

Figure 6: Tailpipe CO_2 emissions (g/year) of the new fleet of Brussels

3.2 The fleet of vehicle registrations of second hand cars

Each year, 60.510 second hand vehicles will enter the market (same amount as in 2010). These vehicles are randomly chosen out of the vehicle fleet of the previous year and it is assumed that it consists only out of petrol and diesel vehicles.

3.3 The total vehicle fleet

The economic crisis is reducing the increase of the total vehicle fleet. Several measures are taken by the BCR, aiming at a reduction of the traffic and consequently the total vehicle fleet. In the meantime, the saturation of roads is reached in the BCR. Taking these evolutions into consideration, it is assumed that the total private vehicle fleet will get stabilized over time (2010-2020) and will have the same annual amount of vehicles (298.593) as in 2010, see Figure 7. The new vehicle fleet will replace the oldest models first. As the oldest vehicles registered in the Brussels Capital Region are petrol vehicles, a slight decrease in petrol vehicles in the total fleet can be seen, contrary to the annual increase of petrol vehicles sales of 10%. However, in the long run the increase of market share of petrol vehicles is visible on the total fleet.

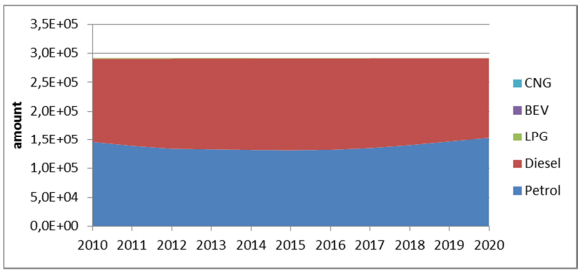

Figure 7: Total fleet of BCR in the 'business as usual' scenario (in # cars)

New vehicles have a significant drop in emissions per kilometre; causing a drop in the total tailpipe CO_2 emissions of the new fleet per year, see Figure 6. However, as new vehicles comprise only a small part of the total vehicle fleet, changes in total yearly emissions are less significant. In Figure 8 the yearly CO_2 emissions are calculated starting from the emissions per kilometre of the different vehicles together with the total driven kilometres per year in the Brussels region (11.100 km) [11]. Total yearly CO_2 tailpipe emissions from private passenger vehicles decrease from 530.929 ton in 2011 to 406.685 ton in 2020. In Table 3 the average CO_2/km for the whole fleet of BCR is given for the period 2010-2020.

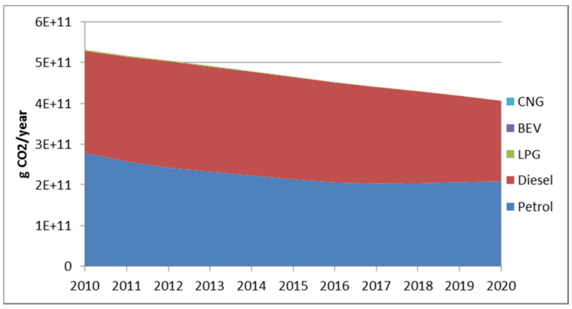

Figure 8: Tailpipe CO_2 (g/year) of the total Brussels vehicle fleet

Table 3: Trend for the average gCO_2/km for petrol and diesel vehicles for the whole fleet of BCR

CO_2 (g/km)	Petrol	Diesel
2010	172	157
2011	167	154
2012	163	151
2013	158	148
2014	153	145
2015	147	142
2016	141	140
2017	136	137
2018	131	135
2019	127	132
2020	123	129

4 Evolution of the Brussels' car fleet in the 'EV-uptake' scenario

In 2011 many car manufactures are starting to launch their first electric vehicles, this clearly shows that the automobile industry believes in a growing potential market share for electric vehicles. In [12] the market potential is predicted in Belgium, using a choice-based conjoint analysis. In May 2011, a large-scale survey was conducted with nearly 1.200 respondents. The goal of the survey is twofold: predict the market potential of (plug in hybrid) electric vehicles in Flanders and comprehend the perception of EVs within the region of Flanders. We conclude the vehicle cost parameters (purchase costs, yearly costs and travel costs) are the most important factors when consumers are in the process of buying a new vehicle. A 6% market share of the newly sold vehicles is predicted for pure electric vehicles, PHEVs could have a market share of around 4%. The climate benefit of the electric driven kilometres has been compared with the results of the business as usual scenario. Figure 9 gives an overview of the market potential of electric vehicles and plug-in hybrid electric vehicles in Belgium for the period 2012-2050. It is assumed that in 2020 the market potential will be 5,4% for BEV's and 3,4% for PHEV's. From this market potential, the new fleet for the 'EV-uptake' scenario can be drafted, see Table 4. Once again it is assumed that the total new fleet of the Brussels Capital Region stays stabilized on 19.597 new vehicles per year. As new vehicles are a small part of the total vehicle fleet, changes in total in the total fleet are more slowly observed. In Table 5 the uptake of electric vehicles in the total fleet can be seen. In 2020 the total fleet of BCR will contain 1,8% BEV's and 1,6% PHEV's.

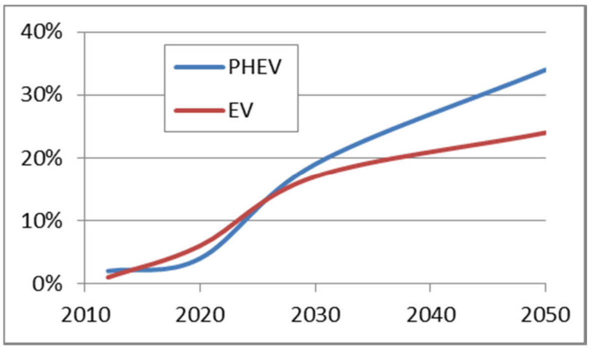

Figure 9: (PH)EV market potential in Belgium, trends from 2012 to 2050

Table 4: Technology split of new vehicles for the 'EV-uptake' scenario (in # cars)

	Petrol	diesel	BEV	PHEV	Total
2010	8167	11426	0	0	19597
2011	9310	10283	0	0	19597
2012	10007	8959	259	368	19597
2013	10858	8031	308	396	19597
2014	11605	7193	368	427	19597
2015	12256	6437	439	461	19597
2016	12816	5756	525	496	19597
2017	13290	5141	627	535	19597
2018	13682	4586	749	576	19597
2019	13993	4085	894	621	19597
2020	14226	3631	1066	670	19597

Table 5: The uptake of electric vehicles in the total fleet for the 'EV-uptake' scenario (in% of total vehicles=298.593)

	BEV	PHEV	Petrol	diesel
2010	0%	0%	50%	50%
2011	0%	0%	48%	52%
2012	0,1%	0,1%	46%	54%
2013	0,2%	0,3%	45%	54%
2014	0,3%	0,4%	45%	54%
2015	0,5%	0,6%	44%	54%
2016	0,7%	0,7%	44%	54%
2017	0,9%	0,9%	45%	53%
2018	1,1%	1,1%	47%	51%
2019	1,4%	1,3%	48%	49%
2020	1,8%	1,6%	50%	47%

5 Comparison of two scenario's

In the previous description of the two scenarios, the yearly tailpipe CO_2 emissions were calculated taking the variability of the vehicles in the fleet into account. To be complete, this part will introduce the life cycle CO_2 emissions of the whole fleet.

The 'Business as usual' scenario and the 'EV-uptake' scenario differ in the yearly market shares of the different vehicles technologies, explained in Table 2 en Table 4. In the 'EV uptake' scenario a yearly growth of newly registered electric vehicles is witnessed, expressed in Figure 10. The yearly life cycle CO_2 emissions from the 'Business as usual' scenario are shown in Figure 11. Figure 8 is similar to Figure 11, however, the first figure only shows the tailpipe emissions, the second figure shows the life cycle emissions (including manufacturing, fuel production, tailpipe and end-of-life treatment). The yearly life cycle CO_2 emissions decrease from 690 kton CO_2 in 2010, 604 kton CO_2 in 2015 to 528 kton CO_2 in 2020. The decrease in CO_2 emissions in the 'Business as usual' scenario is explained by the decrease of the tailpipe emissions of the conventional vehicles, where the average CO_2/km decreases from 172 g CO_2/km (petrol) and 157 g CO_2/km (diesel) in 2010 to 123 g CO_2/km (petrol) and 127 g CO_2/km (diesel) in 2020. The yearly life cycle CO_2 emissions from the 'Business as usual' scenario are compared with the yearly life cycle CO_2 emissions from the 'EV uptake' scenario in Figure 12. In other words, the life cycle CO_2 emissions from the cumulative amount of electric vehicles in the total fleet are compared with the life cycle CO_2 emissions of the 'Business as usual' scenario.

In the 'EV uptake' scenario the yearly total CO_2 emissions decrease from 690 kton CO_2 in 2010, 600 kton CO_2 in 2015 to 518 kton CO_2 in 2020. Investing in an 'EV uptake' scenario leads to a yearly emission reduction of 10 kton CO_2 in 2020 for the Brussels Fleet.

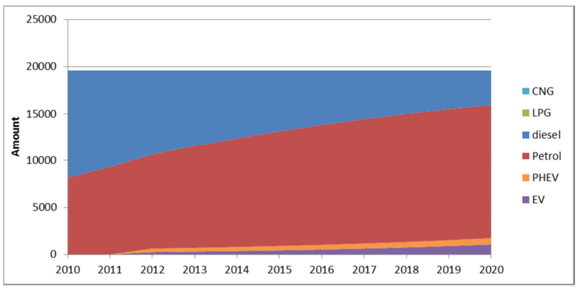

Figure 10: Evolution of the new car fleet of Brussels in a 'EV uptake scenario'

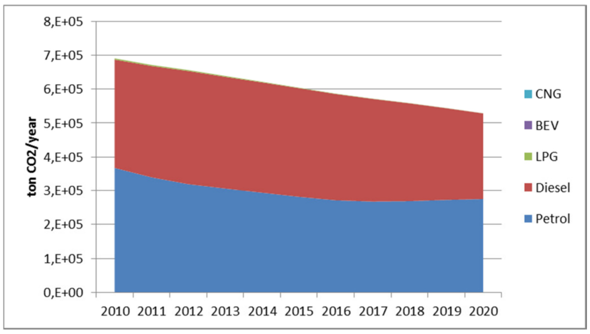

Figure 11: Yearly life cycle CO_2 emissions from the 'Business as usual' scenario for the full Brussels fleet

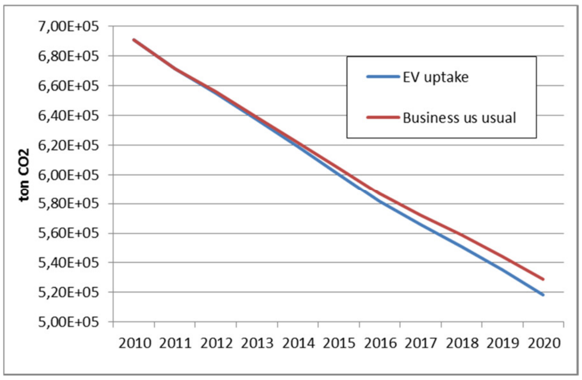

Figure 12: Comparison of the life cycle CO_2 emissions for the whole Brussels fleet

6 Conclusions

A BEV running on electricity produced in Belgium has the lowest climate change impact, when compared with other vehicles. Like all other vehicle technologies, the use phase of a BEV is determining the overall result. When considering climate change impact, the electricity consumption during the use phase is the main contributor to the total impact of a BEV. However, a full LCA is needed as the manufacturing of the vehicle and the EV specific components, such as Lithium batteries, have an important impact on climate change. Due to high recovery rates of the main materials, the End-Of-Life treatment has a positive effect on the climate change impact of the whole life cycle of a Lithium battery.

An LCA comparison, Figure 3, showed that a petrol vehicle emits a total of 177g CO_2/km and a diesel emits 127g CO_2/km compared to 59g CO_2/km for a BEV in 2010.

In 2020, when 20,3% of Belgian electricity will be produced with renewables, the BEV will have an impact of 52g CO_2/km. From these values it is clear that BEV's can play a substantial role in decreasing the climate change effects. However, an LCA of an individual car does not show how fast an uptake of electric vehicles will change the impact of an entire fleet on climate change. The benefit of a large electric vehicle share in a fleet needs to be compared with a future fleet with conventional vehicles that will be more and more energy efficient. For this an LCA of a full fleet was modelled for two scenarios for the Brussels Region: 'Business as usual' and 'EV uptake'. The two different vehicle fleets were compared for the period 2010-2020.

In the 'EV uptake' scenario the yearly total CO_2 emissions decrease from 690 kton CO_2 in 2010 (with no electric vehicles), to 600 kton CO_2 in 2015 (with a cumulative amount of 1374 BEV's and 1652 PHEV's) and to 518 kton CO_2 in 2020 (with a cumulative amount of 5235 BEV's and 4550 PHEV's). Investing in an 'EV uptake' scenario leads to a yearly emission reduction of 10 kton CO_2 in 2020 for the Brussels Fleet. This means that in 2020 it is possible to have a fleet in Brussels consisting of 1,8% BEV's 1,6% PHEV's that reduces 1,9% (or 10 kton CO_2) of the yearly CO_2 emissions when compared to a 'Business as usual' scenario.

A yearly emission reduction is not showing the full benefits of an 'EV uptake' scenario. The cumulative reduction levels can also be calculated. Figure 13 is showing the cumulative reduction of the CO_2 emissions expressed in ton CO_2, when comparing the 'Business as usual' scenario and the 'EV uptake' scenario. In 2020 it is expected that the market potential of BEV has grown to 5,4% and PHEV to 3,4% of the total amount of sold cars in that year. In 2020 this growing, yearly market potential will lead to a cumulative amount of 5235 BEV's (or 1,8% of the total Brussels fleet) and 4550 PHEV's (or 1,6% of the total Brussels fleet). From 2010 till 2020 the uptake of electric vehicles will lead to a total cumulative CO_2 reduction of 48 kton CO_2.

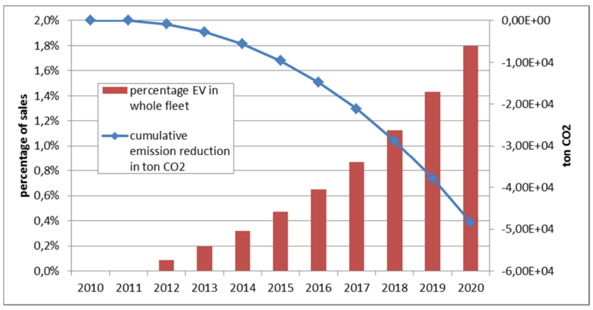

Figure 13: Cumulative emission reduction in ton CO_2

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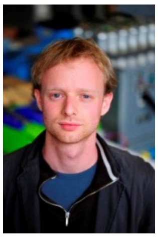

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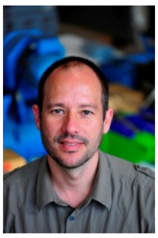
Cathy Macharis is a Professor at the Vrije Universiteit Brussel. She teaches courses in operations and logistics management, as well as in transport and sustainable mobility. Her research group MOSI-Transport and logistics focuses on establishing linkages between advanced operations research methodologies and impact assessment.



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