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Potential for CO_2 equivalent emission reduction in future passenger car fleet scenarios in Europe

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The CO_2 emission performance standards (CO_2 standards) set limits for fleets of new cars sold in Europe at 95 gCO_2/km in 2021 and targeted 59 gCO_2/km in 2030. Furthermore, the European Green Deal aims to reduce at least 55% total greenhouse gas (GHG) emissions in the continent by 2030. These legislations will undoubtedly shape future passenger car fleets in Europe. However, the current standards are solely based on Tank-to-Wheel (TTW) analysis, even though other stages of the product life cycle (LC) can contribute significantly to the overall emissions. Therefore, this paper aims at answering the question: what are possible GHG emission reduction potentials, measured by CO_2 equivalent (CO_2eq), over the whole LC of future EU-wide passenger car fleets that meet the CO_2 standards? Firstly, LC CO_2eq emissions of several state-of-the-art propulsion systems are examined. The technologies considered are internal combustion engine, battery electric, hybrid, plug-in hybrid and fuel-cell. Data on CO_2eq emissions in different LC stages are identified via literature review and own calculations. Reduction potentials of the technologies are addressed for three scenarios, namely 2020 as a basis, 2030, and 2050. Secondly, fleet configurations are defined for the years 2020 and 2030 in order to meet the CO_2 standards, by considering specific TTW CO_2 emissions of the technologies and their shares in the EU passenger car fleet. Finally, LC CO_2eq emissions of possible future fleets are calculated. The results indicate that only increasing the number of low emission vehicles entering the fleet until 2050 will not be sufficient to achieve the transport GHG emission targets. Other measures such as technology improvements, renewable-based electricity grid and e-fuels, need to be taken into account as well. Moreover, TTW-based analysis does not reflect the whole sectoral emissions, thus Well-to-Wheel or even LC emissions should be considered in legislations.

1. Introduction

The European Union aims to reduce emissions significantly by 2030 with at least 55% reduction of greenhouse gas (GHG) emissions in comparison to the 1990 level, as stated in the European Green Deal [1]. As the transport sector contributes to about one fifth of the total greenhouse gas emissions in Europe, being the second largest GHG producer after the energy sector [2], decarbonization in the transport sector has become a crucial measure to achieve stated targets. Within the transport sector, road transport is the main emitter, responsible for more than 70% of the transport GHG emissions [3]. Particularly, passenger cars cause the highest amount of emissions in comparison to other vehicle categories. Therefore, CO_2 standards for passenger cars were introduced in order to bring averaged

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emissions from the passenger car fleet down to a limit 95 gCO_2/km in 2021 (by measuring the 2020 fleet), and to further reduce to a targeted amount of about 59 gCO_2/km by 2030 [4]. Thanks to this legislation, manufacturers around Europe have been improving their technologies, as well as attempt to increase the sales of zero and low carbon emission vehicles (ZLEVs) in their fleets. However, existing legislations regarding emissions of passenger cars only consider emissions occurring during the use phase (TTW). Despite the fact that LC phases of vehicle production, fuel production, electricity production (in the case of electric vehicles), and end-of-life treatment can contribute remarkably to the overall emissions of the vehicles, they are not considered in the current regulations and policies. However, as the European Union sets the vision to become the first carbon-neutral continent in the world, it may become necessary to take the whole LC, expressed via CO_2eq emissions, and the entire mobility system [5], into consideration.

There are several studies on LC assessment of different propulsion systems at the European level, such as [6] [7] [8] [9] [10], as well as reports on how EU-wide passenger car fleets could meet the CO_2 standards [11] [12] [13]. However, studies linking TTW-based legislations and LC emissions of current and future fleets are still missing. This paper intends to fill this gap by 1) identifying CO_2eq emission reduction potentials over the whole LC of EU-wide passenger car fleets that meet the CO_2 standards, and 2) comparing these fleet emissions with the current GHG emission targets for the transport sector.

2. Methodology

Based on real-life data, this paper considers the passenger car fleet in Europe consisting of ICEVs powered by gasoline, diesel, liquefied petroleum gas (LPG), and natural gas (NG), as well as BEVs, PHEVs, HEVs, and FCEVs [14]. Ethanol- and E85-powered vehicles are not considered due to their insignificant share in the fleet [15]. The same applies to HEVs with diesel engines. Currently, FCEVs also just have a small share in new car registration. However, they are included due to the fact that they can play an important role in the future [16].

At first a fleet model is created in order to examine shares of the considered vehicle technologies at present and in the future. In the second step, LC CO_2eq emissions from several drive systems are identified via literature review and own calculations. Next, LC CO_2eq emissions of the whole passenger car fleet are calculated according to two fleet scenarios and then compared to the transport GHG emission targets.

Three scenarios are conducted for different time points according to the CO_2 standards and the Green Deal goals, namely 2020, 2030, and 2050. Even though the 95 gCO_2/km target is set for 2021, the data is in fact accounted for the 2020 fleet and hence scenario 2020. As the CO_2 standards are defined according to the New European Driving Cycle (NEDC), which is replaced by the more realistic Worldwide Harmonised Light Vehicles Test Procedure (WLTP) from 2021 on, it is important to convert the NEDC-based standards. Under the WLTP, the CO_2 fleet limits are approximately 109 g/km and 69 g/km for 2021 and 2030, respectively [17]. WLTP is also the basis for all scenarios.

2.1 Possibilities for future EU-wide passenger car fleet configurations

Data regarding the fleet of new passenger cars and the total number of vehicles-in-use are collected for the period 2010-2020 from difference statistic sources, such as the European Automobile Manufacturers Association (ACEA) [18] [19] and the International Council on Clean Transportation (ICCT) [20]. By using a simple stock-flow analysis and the historical data, numbers of different vehicle technologies are calculated.

Possible new passenger car fleet configurations to meet the CO_2 standard are addressed for 2020 and 2030 by combining EU-averaged specific CO_2 (TTW-based) emissions of the considered technologies and their respective shares in the new car sales in the market. Data from the fleet of 2019 is set as a reference to validate the calculations based on available datasets from the European Environment Agency [15]. Shares of car sales are collected for 2020 and are assumed for 2030 and

2050 [21] [22] [23]. Note that as 2020 is counted as the "transition" time, only 95% of the fleet is used for calculating the fleet-average emissions. A "super credit factor" is also considered, based on the EC regulation [4]. In order to examine how different shares of the technologies will affect the whole passenger car fleet emissions in 2050, two fleet scenarios are created for 2030, namely FS1 and FS2. In FS1, the shares of technologies in the new car fleet are assumed to meet the CO_2 standard. On the other hand, in FS2, an extreme case is considered, in which ZLEVs will be accounted for 90% of the new car fleet.

2.2 Life cycle CO_2eq emissions of different propulsion systems

This paper focuses on the LC emissions of mid-size passenger cars in the European context. To extract vehicle-specific LC CO_2eq emissions, various studies are compared with each other regarding their boundary conditions (e.g. vehicle mass, electricity mix, battery capacity and materials) in order to derive the most reliable data required for calculations, as shown in Table 1.

Table 1: Main parameters for calculation of LC CO_2 emissions

Parameter	Unit	2020		2030		2050	
		Value	Source	Value	Source	Value	Source
Vehicle lifetime	Km	161000	[18], [13]	168000	Assumed	168000	Assumed
Battery energy density	kg/kWh	4	[24]	3,6	Assumed 10% improvement since 2020	3,2	Assumed 20% improvement since 2020
BEV battery size	kWh	58	[6]	64	[6]	74	[6]
HEV battery size	kWh	2	Assumed	3	Assumed	4	Assumed
PHEV battery size	kWh	10	Assumed	15	Assumed	20	Assumed
Battery production	kgCO_2eq/kWh bat	75	[7]	64	[7]	46	Assumed, based on [7]
Electricity production	gCO_2eq/kWh	439	[6]	254	[6]	20	Assumed 100% renewable
Hydrogen production (NG-based)	gCO_2eq/MJ	96	[9]	88,3	Assumed 8% improvement since 2020	-	
Hydrogen production (electrolysis)	gCO_2eq/MJ	-		137,5	[6]	10	[9] (100% renewable)
Synthetic gasoline production	gCO_2eq/MJ	-		-		57,2 (without CC) -13,8 (with CC)	[6] (20% improvement since 2020)
Synthetic diesel production	gCO_2eq/MJ	-		-		34,4 (without CC) -34,8 (with CC)	[6] (20% improvement since 2020)
Battery recycling potential	kgCO_2eq/kg bat	-3	[25] [26]	-10	Assumed	-12	Assumed

The total mileage is considered to be 161000km for 2020, and 168000km for both 2030 and 2050, as it is argued that ownership models could have an impact on life time expectations, as well as a potential future legislation and/or labelling of LC emissions. Data for glider and powertrain production and their recycling potential are taken from [6], with exception for the production of ICEVs. Due to noteworthy differences in the results, the average of [6] and [8] is used to represent the ICEVs production emissions. ICEVs operated with LPG and NG (alternative fuels) are presented as a joint average (ICEV-AF). The baseline scenario, representing the starting point in 2020, is mainly based on literature. Particularly, TTW emissions of vehicles operated by fossil fuels are taken from the European dataset for 2019 [15], with a 2% improvement for the assumed 2020 scenario. Based on these values, the Well-to-Tank (WTT) emissions are calculated with an online tool of the Austrian Environment Agency [27]. Beside the fossil fuels, the electricity/hydrogen consumption of BEV, PHEV and FCEV is based on the data sheets of individual cars [28] [29] [30].

For the outlook to 2030, a further 3% efficiency improvement is assumed for ICEVs and 8% for the other technologies. These gains are assumed to be acquired through fuel production (e.g. gasoline, diesel, LPG, NG, hydrogen), fuel/electricity consumption and energy density of batteries. All other influencing parameters are still based on previous studies. Regarding FCEVs, an average of NG-based hydrogen and hydrogen produced by electrolysis is calculated for representing the WTT emissions. Additionally, electrolysis process is assumed for hydrogen production, but not for e-fuels, due to the fact that e-fuel production is much less efficient than hydrogen production.

The 2050 scenario is assumed to be the best-case scenario, as assumptions are made to realize the highest emission reduction potential. The efficiency increase is assumed to be 5% for fossil fuel-based technologies and 10% for the others, compared to 2030 level. Vehicle production and recycling, as well as maintenance, are directly based on literature. The fuels used for operating are based on 100% renewable energy (e.g. synthetic gasoline, synthetic diesel, electricity, hydrogen). Furthermore, benefits from carbon capture (CC) are considered for the synthetic fuels, as it is assumed that the amount of carbon contained in those fuels can be bound from the atmosphere or from waste streaming processes. In case of LPG and NG, no e-fuels are considered due to unavailable data. For the depiction of the WTT phase, CO_2 capture is also included.

2.3 Life cycle CO_2eq emissions of potential future fleets

Vehicle-specific LC emissions are combined with their numbers in the fleet scenarios modelled in the first step to extract the LC emissions values for the whole fleets. It is important to note that for a simplified reflection, this paper assumes that the whole passenger car fleet consists of mid-size vehicles. The results are then compared with the European GHG targets for the transport sector published in 2018, namely 929 Mt CO_2eq for 2030 and 337 Mt CO_2eq for 2050 [3]. Even though sectoral emissions are defined as the total amount of GHG emitted in that sector according to IPCC procedures, current transport regulations are based on TTW CO_2 emissions, therefore there are mismatches when different boundaries are considered [31]. Thus, this paper will compare the transport GHG targets to fleet emissions against three system scales: TTW, WTW, and the whole LC. To translate these targets to the passenger car fleet only, this paper assumes that road transport still contributes to about 72% of total transport emissions, and passenger cars are responsible for roughly 44% of road transport emissions, as they are today [3].

3. Results and discussion

3.1 Vehicle-specific CO_2eq emission

Figure 1 shows the LC CO_2eq emissions of average mid-size cars, equipped with the different propulsion systems for all three scenarios. In the 2020 scenario, the BEV clearly outweighs all other drive technologies in terms of CO_2eq LC emissions. Among the fossil fuel-based vehicles there are only narrow differences due to the rather small deviations in efficiency of the ICEs. The PHEV and the FCEV line up in the middle of the field. The outlook to 2030 shows only slight CO_2eq emission reduction potentials for ICE-based drive technologies, while the BEVs carbon footprint can be reduced by more than 37%. This mainly lies in the improvement of the European electricity mix, but also in an increase of battery energy density. For this scenario, conventional fossil fuels are still used for powering the ICEs, because the production of e-fuels by means of electrolysis using the European electricity mix would result in higher CO_2 emissions than the production of conventional fossil fuels. Also, biofuels are not considered due to the high level of sensitivity for conducting an LCA for biofuels. In scenario 2050, since the production process for synthetic diesel is much more efficient than for synthetic gasoline [6], this technology shows the greatest GHG reduction potential for ICE-based technologies. Nevertheless, the BEV provides the lowest LC emissions in the best-case scenario too, with almost half of the emissions compared to 2030. However, the FCEV's carbon footprint can get reduced by more than 67% and thus this type becomes competitive to the BEV.

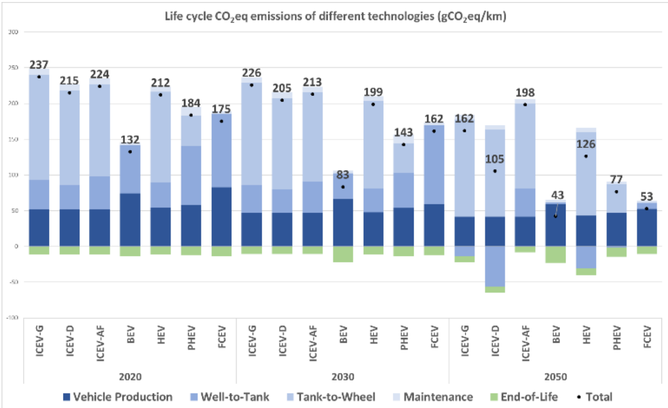

Figure 1: vehicle-specific LC CO_2eq emissions for mid-size cars.

3.2 Fleet CO_2eq emission

3.2.1 New passenger car fleet configurations to meet the emission targets

Table 2 indicates that the new passenger car fleet in 2020 comes closely to the demanded CO_2 standards, with the fleet-calculated emissions stand at 124 gCO_2/km. Shares of BEVs and PHEVs increase more than double and triple in comparison to 2019, respectively. HEVs also witness a remarkable growth, almost two times more than in 2019. Alternative fuel powered vehicles also grow by 23%. In 2030 fleet scenario 1 (2030_FS1), a new passenger car fleet with about 55% ZLEVs and a significant reduction of ICEVs powered by gasoline and diesel will be able to meet the CO_2 standards. Particularly, the shares of ICEV-G and ICEV-D drop by 67%. In this scenario, AF-powered vehicles, rise to account for 10% of the market share. The market for FCEVs will also grow tremendously with a share of 5%. While both BEVs and PHEVs are expected to increase exceptionally to a joint 50% share, share of HEVs will reduce moderately in comparison to 2020. Due to the large shares of ZLEVs, 2030_FS2 demonstrates a tremendous reduction of fleet emission, with more than 50%.

Table 2: Shares in the new passenger car fleet in 2020 (actual) and 2030 (assumed)

Parameter	Technology	2019	2020	2030_FS1	2030_FS2
EU-average CO_2 emission based on WLTP [gCO_2/km]	ICEV-G	151.0	148.0	143.5	143.5
	ICEV-D	157.0	153.8	149.2	149.2
	BEV	0.0	0.0	0.0	0.0
	PHEV	57.7	56.5	51.9	51.9
	HEV	129.2	126.6	116.3	116.3
	FCEV	0.0	0.0	0.0	0.0
	ICEV-AF	121.6	119.2	115.5	115.5

Share of sale volume in the fleet [%]	ICEV-G	58.9	47.5	15.0	0.0
	ICEV-D	30.5	28.0	10.0	0.0
	BEV	2.4	5.2	30.0	40.0
	PHEV	1.6	5.4	20.0	40.0
	HEV	5.9	11.9	10.0	5.0
	FCEV	0.0	0.0	5.0	10.0
	ICEV-AF	1.7	2.1	10.0	5.0
Super credit factor		1	2	1	1
Percentage of the fleet to be considered [%]		100	95	100	100
Fleet-calculated emissions [gCO_2/km] (WLTP)		147.4	124	68.7	32.4
Fleet-average standards [gCO_2/km] (WLTP)		-	109	69	69

3.2.2 Numbers of new vehicles, replacement and vehicles-in-use

Figure 2 indicates the number of new vehicles entering the new passenger car fleet for each scenario. In the present scenarios, the volume of new cars sales increases steadily from 12 million units in 2020 to almost 16 million in 2030 and ends up at roughly 21 million in 2050. While the 2030 fleets in FS1 and FS2 are different in terms of their configuration, the 2050 fleets have the same shares of different technologies. Regarding replacement of cars over the year, the total replaced cars are the same for both fleet scenarios in 2030 and 2050. Yet, FS1 shows higher mounts of replacement for ICEVs and HEVs, while FS2 witnesses more replacement of BEVs, PHEVs, and FCEVs, as illustrated in Figure 3. Due to the differences in in-flow and out-flow, the number of vehicles-in-use is slightly higher in FS1 than FS2 for both 2030 and 2050, as can be seen in Figure 4. The passenger car fleet in the EU rises from 248 million units in 2020 to about 277 million in 2030, and roughly 367 million in 2050. In 2030, ICEVs still contribute to the largest share of the fleet, namely 81% and 75% for FS1 and FS2, respectively. Yet by 2050, only 35% (FS1) or 25% (FS2) of the total passenger car fleet are ICEVs. It is important to note that FS2 points out that even in the case no ICEVs powered by diesel or gasoline will be sold from 2030 on, this technology will still be responsible for at least one fourth of the passenger car fleet by 2050.

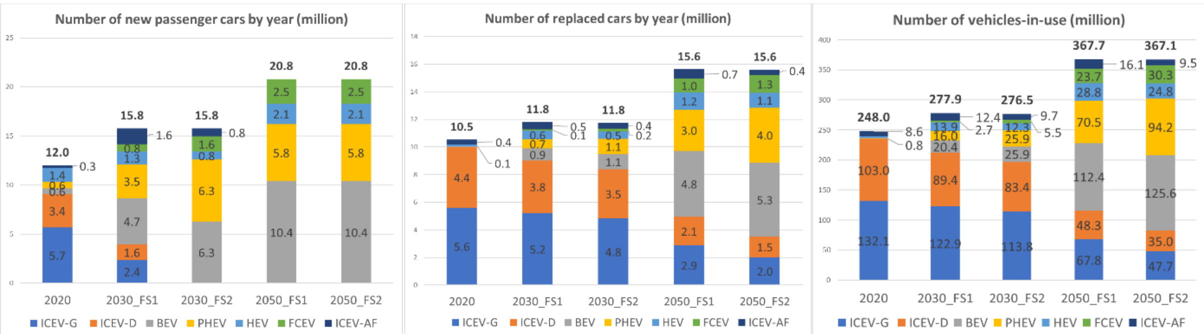

Figure 2: number of new passenger cars. Figure 3: number of replaced cars. Figure 4: number of vehicles-in-use.

3.2.3 Fleet emissions versus transport GHG emission targets

In Figure 5, total fleet emissions per year are illustrated according to three scales. Between 2020 and 2050, LC fleet emissions reduce by 39% in FS1 and 46% in FS2. Meanwhile, TTW emissions decrease by 33% and 46% in FS1 and FS2, respectively. If WTW emissions are considered, then a reduction of 56% in FS1 and up to 64% in FS2 is achieved. Furthermore, if passenger cars will still be responsible for the same share of road transport GHG emissions as today, 2030 and 2050 transport GHG emission targets will not be met. In 2030, passenger car TTW emissions take up to 69% (FS1) and 64% (FS2) of road transport emissions. These shares raise to 91% (FS1) and 87% (FS2) if WTW emissions are considered. When the whole LC emissions are counted, emissions from passenger cars will surpass the transport GHG emission targets.

It is even more problematic for the fleet of 2050, as TTW emissions from passenger cars are higher than the road transport emission targets for both fleet scenarios. So even in the case of FS2, where no new ICEVs enter the fleet from 2030 on, emissions from conventional technologies still impact significantly the passenger car fleet by 2050. Due to advancements of the technologies, e-fuel production, and a higher share of renewable energy in the electricity mix in 2050, passenger cars have in fact lower WTW emissions than their TTW values. It shows that e-fuels in an electricity mix with a high renewable energy share can contribute to the efforts of making transport carbon-neutral.

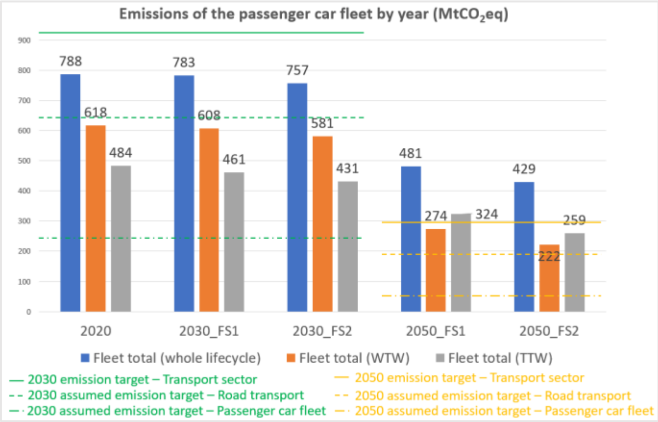

Figure 5: Emissions of the passenger car fleet by year

4. Conclusion

The results show that it is unlikely to achieve the European GHG emission targets for the transport sector if increasing the number of ZLEVs is the only measure. Further improvements of the technologies and efforts to lower GHG emissions from all LC stages are also necessary, as well as a transition to a renewable-based electricity mix coupling with e-fuels production. Additionally, a careful and targeted planning of incentives is in demand. It is important to focus on research to realize the upscale of technologies, such as charging, hydrogen, e-fuels, battery production. Moreover, even though passenger cars emit the highest amount of GHGs in the sector, it is critical that all other vehicle categories and transport modes also reduce their emissions significantly. TTW emissions do not reflect the real sectoral emissions, and therefore broader system boundaries should be considered, such as WTW, or at large, the whole product LC. By 2050, GHG emissions can be reduced by more than 50% if WTW emissions become the basis for calculation. As renewable energy sources contribute more and more to the European grid, e-fuels could play an important role in the future, due to the moderate amount of ICEVs still exist in the fleet by 2050.

The limitations of this paper include the simplification of the fleet configurations, as well as the various assumptions in the LC emission analysis. Future work will address these issues to gain a deeper insight of the topic. Nevertheless, the general statements regarding the impact of different car fleet scenarios on the CO_2 reduction shown in this paper give a holistic overview on the potentials of different technologies.

References

1. European Commission, Communication from the Commission The European Green Deal, 11/12/2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/. [Accessed 08/03/2021].
2. European Environment Agency, Greenhouse gas emissions by aggregated sector, 19/12/2019. [Online]. Available: https://www.eea.europa.eu/data-and-maps/. [Accessed 08/03/2021].
3. European Environment Agency, Greenhouse gas emissions from transport in Europe, 17/12/2019. [Online]. Available: https://www.eea.europa.eu/data-and-maps/indicators/. [Accessed 08/03/2021].

4. European Parliament, Regulation (EU) 2019/631 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles, 17/04/2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/. [Accessed 08/03/2021].
5. H. Brunner, M. Hirz, W. Hirschberg, K. Fallast, Evaluation of various means of transport for urban areas, Energy, Sustainability and Society 8 (9), 2018.
6. N. Hill, S. Amaral, S. Morgan-Price, T. Nokes, J. Bates, H. Helms, F. Horst, K. Biemann, N. Abdalla, J. Jöhrens, E. Cotton, L. German, A. Harris, S. Ziem-Milojevic, S. Haye, Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, European Commission Brussels, 2020.
7. Transport & Environment, How clean are electric cars? T&E's analysis of electric car lifecycle CO_2 emissions, T&E, 2020.
8. M. Wietschel, Klimabilanz, Kosten und Potentiale verschiedener Kraftstoffarten und Antriebssysteme für PKW und LKW, Fraunhofer-Institut für System- und Innovationsforschung ISI, Karlsruhe, 2019.
9. A. Valente, D. Iribarren, D. Candelaresi, G. Spazzafumo, J. Dufour, Using harmonised life-cycle indicators to explore the role of hydrogen in the environmental performance of fuel cell electric vehicles, International Journal of Hydrogen Energy 45 (47), 2020, pp. 25758-25765.
10. S. Merschak, P. Hehenberger, J. Bachler, A. Kogler, Data relevance and sources for carbon footprint calculation in powertrain production, International Conference on Product Lifecycle Management - Product Lifecycle Management Enabling Smart X Rapperswil, 2020.
11. International Council on Clean Transportation, CO_2 emissions from new passenger cars in Europe: Car manufacturers' performance in 2019, ICCT, 2020.
12. Deloitte, Cutting CO_2 emissions from passenger cars - Towards a greener future for the European automotive industry, Deloitte, 2020.
13. B. Witkamp, R.-v. Gijlswijk, M. Bolech, T. Coosemans, N. Hooftman, The transition to a Zero Emission Vehicles fleet for cars in the EU by 2050, EAFO project, 2017.
14. European Automobile Manufacturers Association, Fuel types of new passenger cars, 01/08/2020. [Online]. Available: https://www.acea.be/statistics/. [Accessed 05/03/2021].
15. European Environment Agency, CO_2 emissions from new passenger cars, 23/06/2020. [Online]. Available: http://co2cars.apps.eea.europa.eu/. [Accessed 12/02/2021].
16. Fuel Cells and Hydrogen , Hydrogen Roadmap Europe, Publication Office of the European Union Luxembourg, 2019.
17. The International Council on Clean Transportation, 2020–2030 CO_2 standards for new cars and light-commercial vehicles in the European Union, ICCT, 2016.
18. European Automobile Manufacturers Association, Size and distribution of the EU vehicle fleet, 01/02/2021. [Online]. Available: https://www.acea.be/statistics/. [Accessed 14/02/2021].
19. European Automobile Manufacturers Association, Vehicles in use in Europe, ACEA, 2021.
20. The International Council on Clean Transportation, European Vehicle Market Statistics Pocketbook 2020/21, ICCT Europe, 2020.
21. A. Tsakalidis, C. Thiel, Electric vehicles in Europe from 2010 to 2017: is full-scale commercialisation beginning? - An overview of the evolution of electric vehicles in Europe, Publications Office of the European Union Luxembourg, 2018.
22. A. Mayyas, M. Mann, Manufacturing competitiveness analysis for hydrogen refueling stations, International Journal of Hydrogen Energy 44 (18), 2019, pp. 9121-9142.
23. Transport & Environment, Roadmap to decarbonising European cars, European Federation for Transport and Environment AISBL, 2018.
24. R. Haslinger, Mehr Effizienz und Reichweite, Netzintegration, 2017, pp. 113-115.
25. M. Buchert, J. Sutter, Aktualisierte Ökobilanzen zum Recyclingverfahren EcoBatRec für Lithium-Ionen-Batterien, Öko-Institute E.V. Darmstadt, 2016.
26. M. Buchert, J. Sutter, Aktualisierte Ökobilanzen zum Recyclingverfahren LithoRec II für Lithium-Ionen-Batterien, Öko-Institute E.V. Darmstadt, 2016.
27. Umwelt bundesamt, Berechnung von Treibhausgasen (THG)-Emissionen verschiedener Energieträger, 10/2019. [Online]. Available: https://secure.umweltbundesamt.at/co2mon/co2mon.html. [Accessed 10/03/2021].
28. ADAC, VW ID.3: Das Volks-Elektroauto im ADAC Test, 03/02/2021. [Online]. Available: https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/vw/vw-id-3/. [Accessed 10/03/2021].
29. ADAC, Volvo XC40 T5 Twin Engine: Das kann der Plug-in-Hybrid, 27/10/2020. [Online]. Available: https://www.adac.de/rund-ums-fahrzeug/autokatalog/marken-modelle/volvo/volvo-xc-40/. [Accessed 10/03/2021].
30. Toyota, Mirai Basis, [Online]. Available: https://www.toyota.de/automobile/mirai/. [Accessed 18/03/ 2021].
31. Innovation for Life, Consideration of alternative approaches to regulating CO_2 emissions from light duty road vehicles for the period after 2020, TNO Delft, 2013.