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Life cycle assessment of electrification of heavy-duty vehicle

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Summary

Heavy-duty vehicles significantly contribute to the total greenhouse gas emissions of the transportation sector. Electrification of heavy-duty drivetrains is one of the technological solutions to decarbonize. However, the total costs of electric and conventional heavy-duty vehicles remains a big hurdle. The European H2020 project ORCA, partnered with several research institutes, original equipment manufacturers (OEM) and vehicle manufacturers, is addressing the cost issue by optimally downsizing the key components such as engine, battery, electric motor, etc and also by increasing the efficiency of the powertrain. The design optimization would render the electrified heavy duty vehicle to become cost competitive to the conventional counterparts. This paper aims to study how this optimally downsized electrified heavy-duty vehicle performs environmentally from a life cycle perspective. Vehicles will operate in a dual mode which is conventional and hybrid mode outside of the described zero-emission zone and in battery mode inside the zero-emission zone. Therefore, in the operational stage, the emissions will come from both the tank-to-wheel part, the tailpipe emissions, as well as from the well-to-tank part, the electricity to charge the battery and the production of the diesel that is consumed. In the total lifecycle of the heavy-duty vehicle, the plug-in hybrid bus emits 13% less greenhouse gas emissions (GHG) compared to diesel bus when charged with the current EU electricity mix. Further reduction of lifetime GHG emission can be done if energy production is less carbon intensive.

Keywords: LCA (Life Cycle Assessment), heavy-duty, HEV (hybrid electric vehicle), bus, environment

1 Introduction

Transportation remains one of the dominating sectors where a significant amount of GHG emission is taking place. In the US although the heavy-duty vehicles account for only 1% of the total highway transport, they are accountable for 17% of petroleum and 12% of oil consumption[1]. In EU heavy-duty vehicles such as lorries, buses and coaches produce a quarter of GHG emission in the transportation sector, and they also account for 6% of the total GHG emission in EU [2]. One promising way to deal with this issue is to increase the usage of electric or plug-in hybrid vehicles. Other than low environmental emission it has advantages like energy efficient and quiet operation which is ideal for emission-free zone [3]. Moreover, due to zero emission in electric mode, it improves the local air quality. However, one of the main issues of such electrified heavy-duty electric vehicle is cost. European project ORCA is mainly about manufacturing heavy-duty hybrid vehicle which will be cost compatible with the conventional one. Furthermore, it aims to improve the powertrain by 5% and the electric range by 30km. It also has an ambitious goal of reducing fuel consumption by 40% by downsizing the ICE by at least 50%. This will result in decreasing the total cost of ownership [4]. Purpose of the paper is to observe how the downsized vehicle environmentally performs by using the Life Cycle Assessment (LCA) method.

2 State of the art

Many articles are published addressing the life cycle assessment of passenger cars. There are many details on the inventory analysis and various assessment of impact analysis of it. However, compared to passenger cars, there are not many detailed LCA studies for heavy-duty vehicles. This state of the art study aims to compile notable works on heavy-duty vehicles studies and focusses on following key topics.

- Heavy duty vehicle type (Truck or bus)
- Heavy duty technology (conventional, hybrid, etc) they studied
- Region of study
- Lifetime in a year or in km
- LCA stages covered
- Data collection method for Life Cycle Inventory (LCI)
- Software used
- Impact assessment

M. Martinez et al. focused on long-haul transportation of heavy-duty truck in the European context and potential environmental benefit if the power train is substituted by hybrid [5]. Their approach was full LCA. However, the disposal phase is neglected as it has an insignificant contribution to GHG impact compared to use stage. Literature survey, database, and simulation results of the heavy-duty truck model was mainly used for Life Cycle Inventory (LCI). Based the real driving cycle and lifetime mileages they selected, the hybrid truck saves about 4.34 tCO_2 eq per ton of cargo compared to internal combustion engine counterpart.

Although in this manuscript [6] they mentioned LCA in the title, but they focused mainly on well to wheel perspective of a battery electric bus with a comparison with the diesel-powered bus. Full LCA is done for diesel cycle and electricity production which is in the WTW stage. With the Korean electricity mix, they also reach in the same conclusion that battery electric vehicles perform better with respect to diesel buses at least in WTW part.

In this study [7], they compared different types of the alternative heavy-duty truck with a hybrid LCA method. They found out that CNG based truck has no significant difference regarding environmental impact compared to other conventional counterparts. The electric truck performs much better in life cycle performance provided that the electricity source is from renewable. Battery capacity is not a major cost component according to A. Lajunen in their study [8]. According to them, the charging method has a major role in lifecycle cost. Opportunity charges have the highest cost and end station charging bus at the lowest cost. Using the GREET model [6] and [9] come to the same conclusion that, in term of energy consumption and emission battery electric city bus has advantages but holds uncertainty in driving range. However, [9] also stated that the hybrid is the best choice of bus operation in terms of performance on life-cycle cost and emission.

Lots of attention are given on electric buses in China. Recently Shenzhen became the world first city to host all-electric public transport, and other states are following this trend. In this interesting study [10], they aim to estimate GHG emission for electric bus compared to traditional diesel buses using streamlined LCA method. For life cycle inventory data, they mostly rely on real-world measurement from a various field test, pilot project. They also used databases like Ecoinvent and local databases like CLCD. Emission data for diesel were collected by on-road sensor for two months and also the energy consumption is collected from two-month pilot project by the Macau government. For electric bus charging, they considered charging and

Table 1: Summary of state of the art study

Heavy Duty type	Technol -ogy	Region	Life time year / life time km	Method-ology	Data collection method	Software used	Impact assessment	Ref.
Trucks	Hybrid (comparative study other technology)	Germany	8 years, 104,0000 km	LCA stages Manufacture and WTW	From literature and ecoinvent	openLCA	Hybrid: 1.45 kg CO_2 eq/km	[5]
Bus	Battery electric	South Korea	na	Use stage (WTW)	Experiment and GREET	GREET 2016	Battery electric : 0.211 kg CO_2 eq/km Diesel: 1.8 kg CO_2 eq/km	[6]
Bus	Hybrid and electric bus	China	50,000 km	WTW	From experiment and GREET	GREET	Hybrid: 0.912 CO_2 eq/km Electric: 0.853 CO_2 eq/km Diesel – 1.14 CO_2 eq/km	[9]
Bus	Battery Electric	China	na	Streamlined LCA	Real world test data, ecoinvent and CLCD database	Crystal ball soft.	Diesel Heavy duty bus: 1.28 CO_2 eq/km EV bus average :0.977 kg CO_2 eq/km	[10]
Bus	Electric (compared with CNG)	China	na	WTW	GREET	GREET	Diesel:1.06 CO_2 eq/km Hybrid: 0.75 kg CO2 eq/km	[11]
Bus	Battery Electric compared with diesel bus	China	na	WTW	Experiment and GREET	GREET	Battery electric: 1.1 kg CO_2 eq/km Diesel: 1.4 CO_2 eq/km	[12]
Truck	Mixed hydrogen-diesel truck	Canada	287,278 km/year for 20 year	LCA	From Fleet LCA database	Fleet LCA	Diesel: 1.95 CO_2 eq/km Dual mode avg : 1.3 kg CO_2 eq/km	[13]

electricity distribution losses and found out it contributes a significant upstream GHG emission. When charging and electricity distribution losses are not considered battery electric bus could reduce 1.78% of GHG compared to diesel buses. This is due to the high GHG emission factor of the electricity mix. However, under this electricity mix, they concluded that Battery electric bus is not environmentally beneficial when charging and electricity distribution loss are considered.

Another study from Renjie Wang, [11] dug deeper in WTW study in the context of China. Use of HEV can reduce petroleum and fossil energy use by 20% according to their findings. Boya Zhou et al. along with life cycle CO2 emission calculation they also focused on traffic condition, passenger load and air condition impact and system efficiency [12]. They stated that battery electric bus performs better in worst condition like heavy traffic, AC operation and passenger load. They also proved system charging efficiency has a direct co-relation on WTW emission; hence great importance is recommended in system efficiency improvement.

Other than an electric-diesel hybrid solution, this study [13] experimented hydrogen- diesel solution. They stated that when diesel is substituted partially by hydrogen performance and efficiency increases. In their study, they evaluated life cycle assessment of it. Climate change and criteria air contaminant (CAC) are chosen as impact assessment. In WTW analysis they considered the full life cycle of diesel, and for hydrogen, they skipped the hydrogen production stage out of the scope. This is because they considered the source of hydrogen is from waste by-product of different industry. Compared with only diesel mode, they tested 30%, 40%, and 50% dual i.e. diesel-hydrogen mode. The higher the ratio of hydrogen and diesel greater the impact is. With an equal amount of diesel and hydrogen, they found 47% reduction of GHG emission.

In the Table 1 literature study results are summarized. All the literature we came across are on hybrid heavy-duty vehicles and not on plug-in hybrid heavy-duty vehicles. Only two of the studies [5] and [6] included the manufacture stage LCA. However they are not detailed to the level of components. Most of the study here focused more on WTW stage. End of life stage skipped in all of the studies as it has an insignificant contribution to GHG emission with respect to other stages. GREET is found to be popular software among the authors to calculate emission related to well to wheel stage. Lifetime GHG emission rate of diesel-powered heavy duty vehicle for most of the papers are in the range of 1.06 kg CO_2 eq/km to 1.95 kg CO_2 eq/km and for hybrid heavy-duty vehicle it is in the range of 0.75 kg CO_2 eq/km to 1.45 kg CO_2 eq/km.

3 Goal and scope

The objective of the underlying paper is to see how downsized, electrified passenger bus which is compatible with a conventional passenger bus, perform environmentally throughout its life cycle.

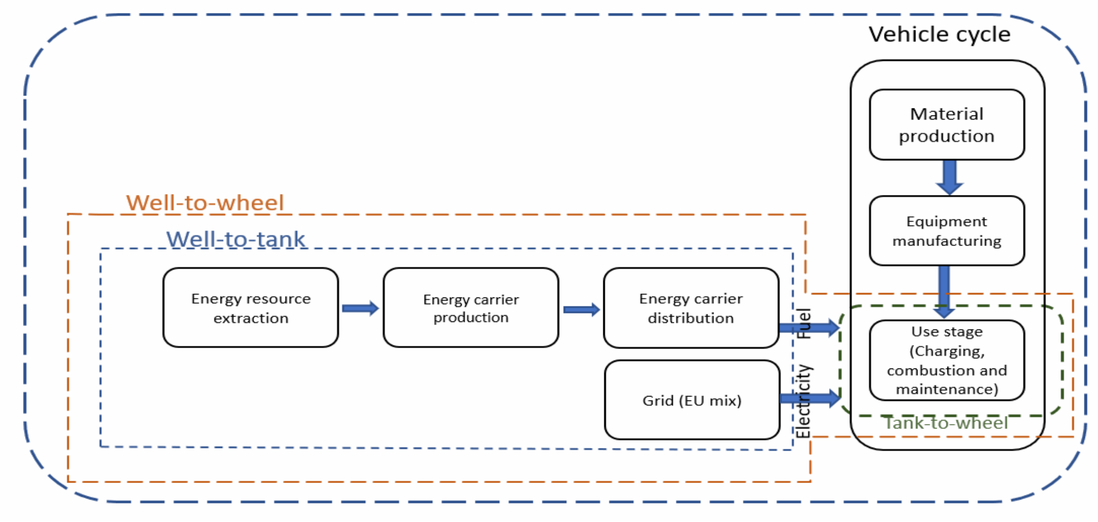

Figure 1: System boundary of the study

The result will be used by the OEMs to optimize the vehicle manufacturing process by finding the optimal sizing of the ICE engine, motor, and battery. The study is a full life cycle assessment, from cradle grave study, it includes all the stages of the bus except the disposal stage. In very few literatures this stage is included and most of the studies don't include this stage for vehicle LCA study because it has insignificant impact compare to the magnitude of impact in use stage [5]. The vehicle will run in a dual mode which is conventional mode and battery mode.

In the zero-emission zone, the vehicle will run on full battery mode as there is no tailpipe emission in this mode. Other than zero emission zone the vehicle will run on conventional and hybrid mode. This dual mode operation is depicted in Figure *3*. Therefore, in the operation stage, the vehicle takes energy from mainly two sources, i.e., fuel for the ICE engine and electricity for charging the battery. The overall system boundary of the study is shown in Figure *1*. The upstream emission of the energy sources which are fuel and electricity, also known as well to the tank (WTT) will also be in the scope of the study. Energy conversion takes place in the bus which is labeled as tank to wheel (TTW). In conventional mode, TTW has emission whereas in battery mode in the zero-emission zone it has zero-emission. The functional unit thus would be the manufacturing and use of a heavy-duty hybrid bus running on combined SORT cycle for seven years with a total mileage of 223,650 km.

4 Life cycle inventory

Three main stages are included, namely the production stage, use stage and end of life stage. Data gathering for each stage is needed to perform LCA. In this study, the end of life stage is skipped as mentioned earlier. In this section short description of the Life Cycle Inventory (LCI) for manufacturing and use stages are summarized.

4.1 Manufacturing:

In the literature study, it is found that most of the LCA studies done on heavy duty vehicle skipped the manufacturing stage due to lack of data. Detailed manufacturing data for each powertrain component was not available in details the literature studies. In the Ecoinvent database, electric passenger car of Brusa has detailed manufacturing database to the level of each power train components. Powertrain components like electric motor, inverter, power distribution unit, converter, charger, cable, and battery has been adapted and scaled up to match the heavy-duty vehicle. Their weight has been assumed based on different OEM website, literature and databases. In Table 2 the life cycle inventory of the components of the heavy-duty vehicles are listed with their amount.

Table 2: LCI of manufacturing

Materials	Amount	Unit
Cable	15	m
Charger	10	kg
Converter 100 kW	10	kg
Electric motor 100 kW	80	kg
Internal combustion engine 129 kW	387	kg
Inverter 100kW	30	kg
Power distribution unit 100kW	41	kg
Battery Li-ion	800	kg
Glider	5000	kg

Components are suitable for the 100kW electric drivetrain. The technology of the battery used here is Li-ion technology. According to the ecoinvent database, the battery's cathode is LiMn2O4 and electrolyte is LiPF6.

4.2 Well to Wheel

During the operation phase, the vehicle has no tailpipe emission when it is in battery mode. The vehicle is proposed to run 30km in battery mode in the no emission zone as shown in Figure 3. In that case, electricity consumption data will be used to find out WTT upstream emission from charging the battery to that amount. When the vehicle is in conventional mode tailpipe emission will take place from its ICE engine. Therefore, two upstream emissions are considered. First is all the associated upstream emission of electricity production to charge the battery. To evaluate this, the European electricity supply mix has been used. The next well to tank emission is evaluated for diesel. The ecoinvent database of European context is used to formulate this. The amount of electricity and fuel need in a total lifetime are formulated from the model developed in [14] in Matlab and Simulink. The model's driving cycle is based on standard SORT cycle as shown in Figure 2.

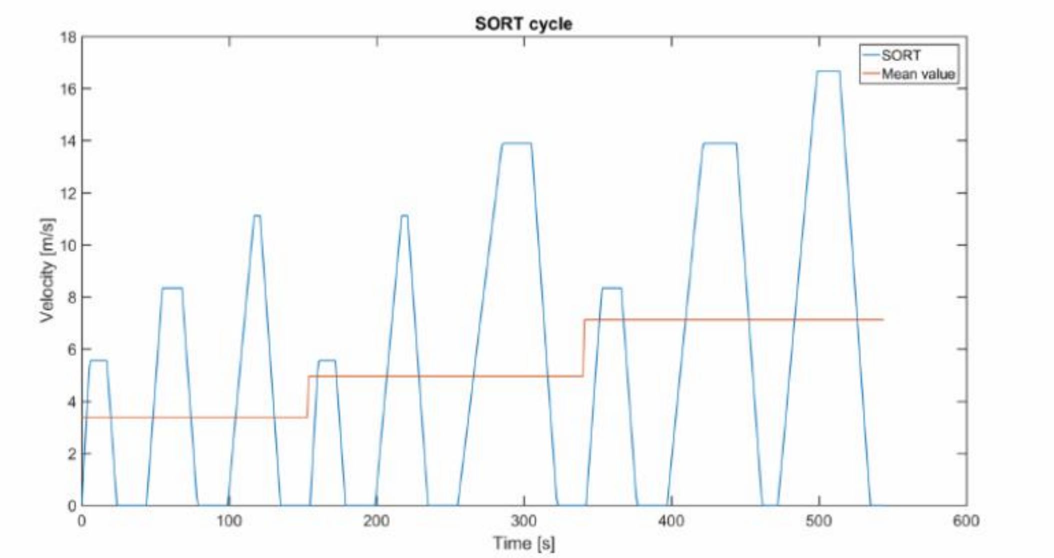

Figure 2: Speed profile of SORT cycle combination [14]

During the simulation power requested for traction is split between electric motor and ICE by a factor. That factor is calculated using the equivalent consumption minimization strategy (ECMS) which minimize the total equivalent consumption each time when a new driving cycle starts.

Table 3: WTT processes

Process	Unit	Database version
Electricity, low voltage (Europe without Switzerland)	kWh	Ecoinvent 3
Diesel (Europe without Switzerland)	kg	Ecoinvent 3

From the model is has been found that in total lifetime 199500 kWh of electric energy needed to fulfill the driving of 30 km in battery mode along with hybrid mode other time. For driving in conventional mode, a total of 20405 kg of diesel needed in a lifetime. To determine the WTT emission for each consumption processes of them are shown in Table 3.

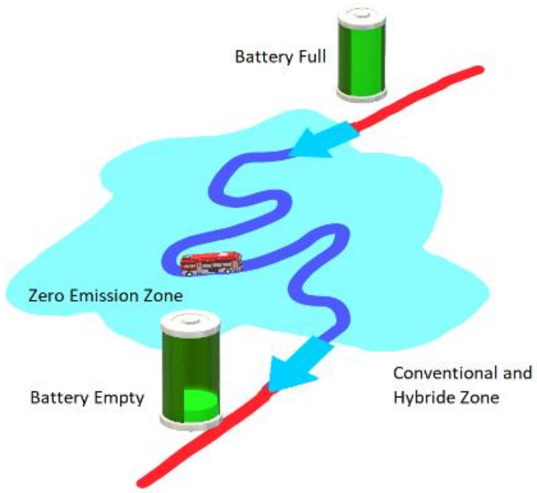

Figure 3: Dual mode of operation for supporting zero-emission zones

Tank to wheel is the actual emission takes place in the tailpipe. The vehicle has tailpipe emission only when it drives in ICE mode. To calculate the emission from the vehicle emission map of a diesel engine is needed. The emission map of engine out has been given by partner OEMs in this project. That map has been used to evaluate the fuel need and the emission occurred.

5 Results and discussions: Impact assessment

The vehicle is modeled in SimaPro 8.5. It has built-in ecoinvent database and number of impact assessment methods. The model is run considering seven years of lifetime with 223, 650 km of lifetime mileage. Total lifetime GHG emission found to be 221 tCO_2 eq which results in 0.990 kg CO_2 eq/km. Total emission due to manufacturing the vehicle is around 49.6 tCO_2 eq. Contribution of each component is summarized in Figure 5. About 70% of the GHG contribution came from the glider which includes the body of the vehicle, the steering, braking and suspension system, tires, cockpit equipment (seats, belts, etc.) and non-propulsion related electronics. Major contribution of GHG emission on the production of the glider came from the processes of reinforcement steel and electricity consumption of medium voltage. Then in the powertrain main environmental load comes from the battery which is around 5.5 tCO_2 eq.

Table 4: Carbon intensity of countries generated from SimaPro 8.5

Country	Carbon intensity (kg/kWh)
Belgium	0.25
Denmark	0.41
Germany	0.63
France	0.06
Italy	0.43
Poland	1.08
Netherlands	0.64
Norway	0.03
Sweden	0.05
Switzerland	0.13
EU average	0.48

In Figure 4, for the plug-in hybrid bus, it is seen that the emission of the use stage is higher than the manufacturing stage. Among the use stage, well to tank emission accounts for the highest climate change impact which is around 56% of the total use stage emission — then followed by the tailpipe emission which is 37%. Upstream emission of diesel, i.e. WTT of diesel comparatively has less contribution to GHG emission. According to the assumption of the manufacturing component defined in Table 2, it is seen that the manufacturing process entail 22% of the total GHG emission of a total lifetime of the vehicle.

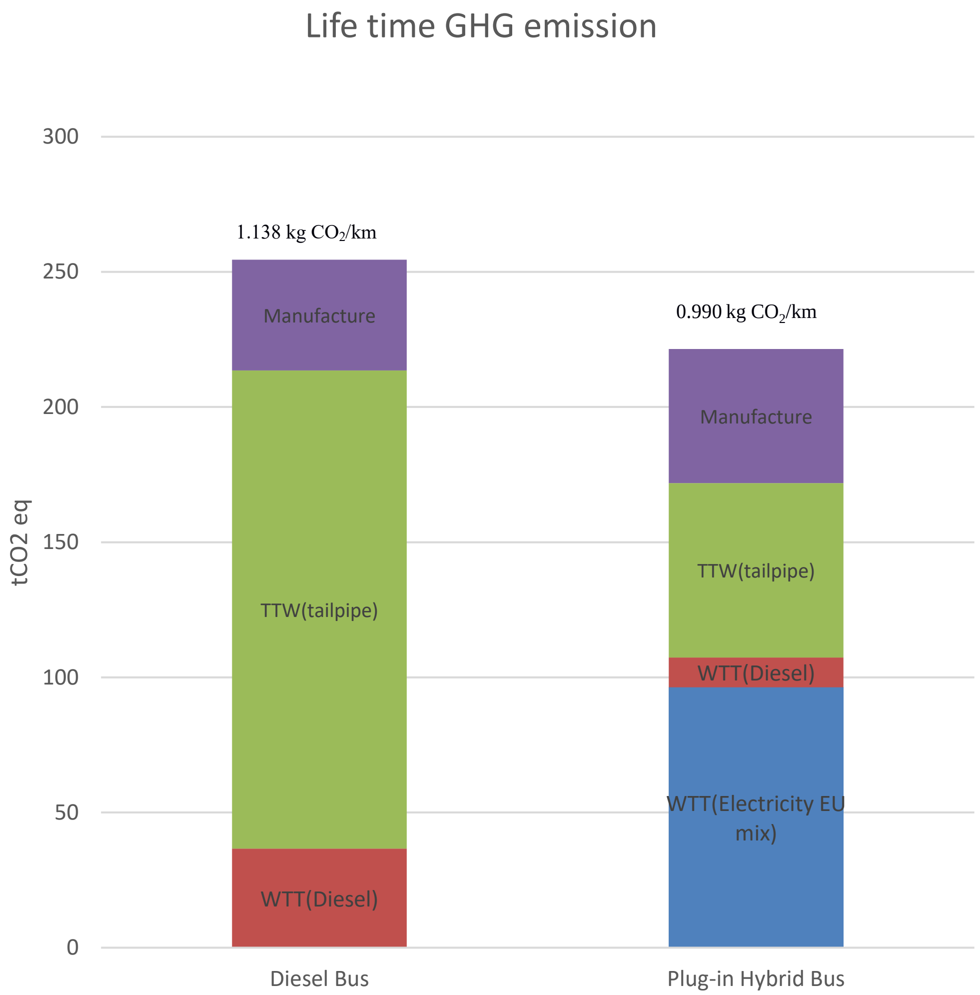

Figure 4: lifetime emission comparison with conventional bus

For benchmarking purpose, a similar conventional bus model is built in the SimaPro with the Ecoinvent database. Average fuel economy of 30l/100 km taken from the OEM [15]. To drive 226, 650 km of a lifetime, 67059 kg of diesel needed. WTT emission is calculated from SimaPro for the diesel and TTW emission results are gathered from the simulation.

Here in Figure 4 it is seen that the major GHG emission of the conventional bus came from the tailpipe emission. The total GHG emission is 255 tCO_2 eq which is around 1.14 kg CO_2 eq/km. This is about 13% more than plug-in hybrid technology. Here it is worth mentioning again the major contribution of GHG emission of the plug-in hybrid bus is from WTT emission of electricity production from European electricity mix. Therefore, clean electricity production can reduce overall GHG emission. In **Error! Reference source not found.** comparing with the diesel bus, lifetime emission of the plug-in hybrid bus of different electricity mix of EU countries are shown.

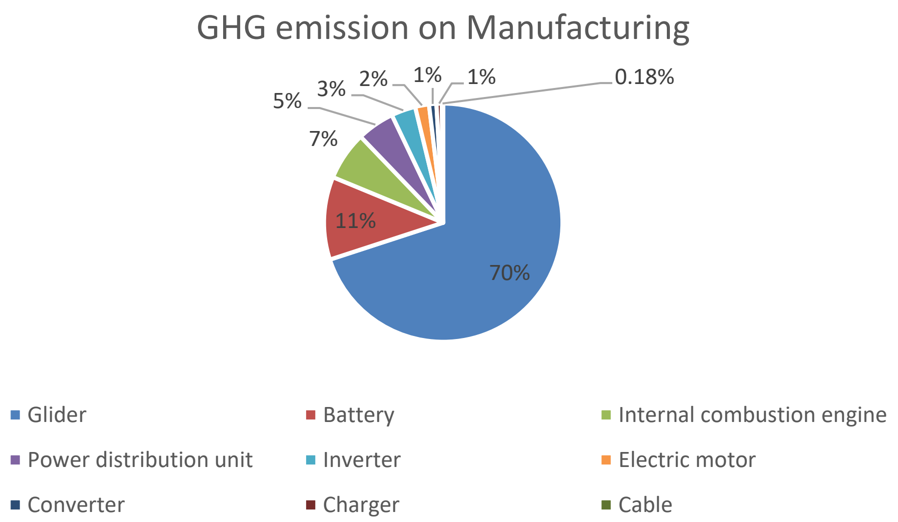

Figure 5: GHG emission on manufacturing

Carbon intensity of some of the European countries are listed in **Error! Reference source not found.**. This data is generated from Ecoinvent processes. From the table, it is clear that countries with low carbon intensity like Norway, Sweden and France which are mostly hyrdo and nuclear powered have low lifetime GHG emission to charge the plug-in hybrid bus. In the context of the Netherlands and Germany electricity mix, which has almost the same carbon intensity of 0.63 kg/ kWh, plug-in hybrid bus's life time emission are nearly the same with diesel bus.

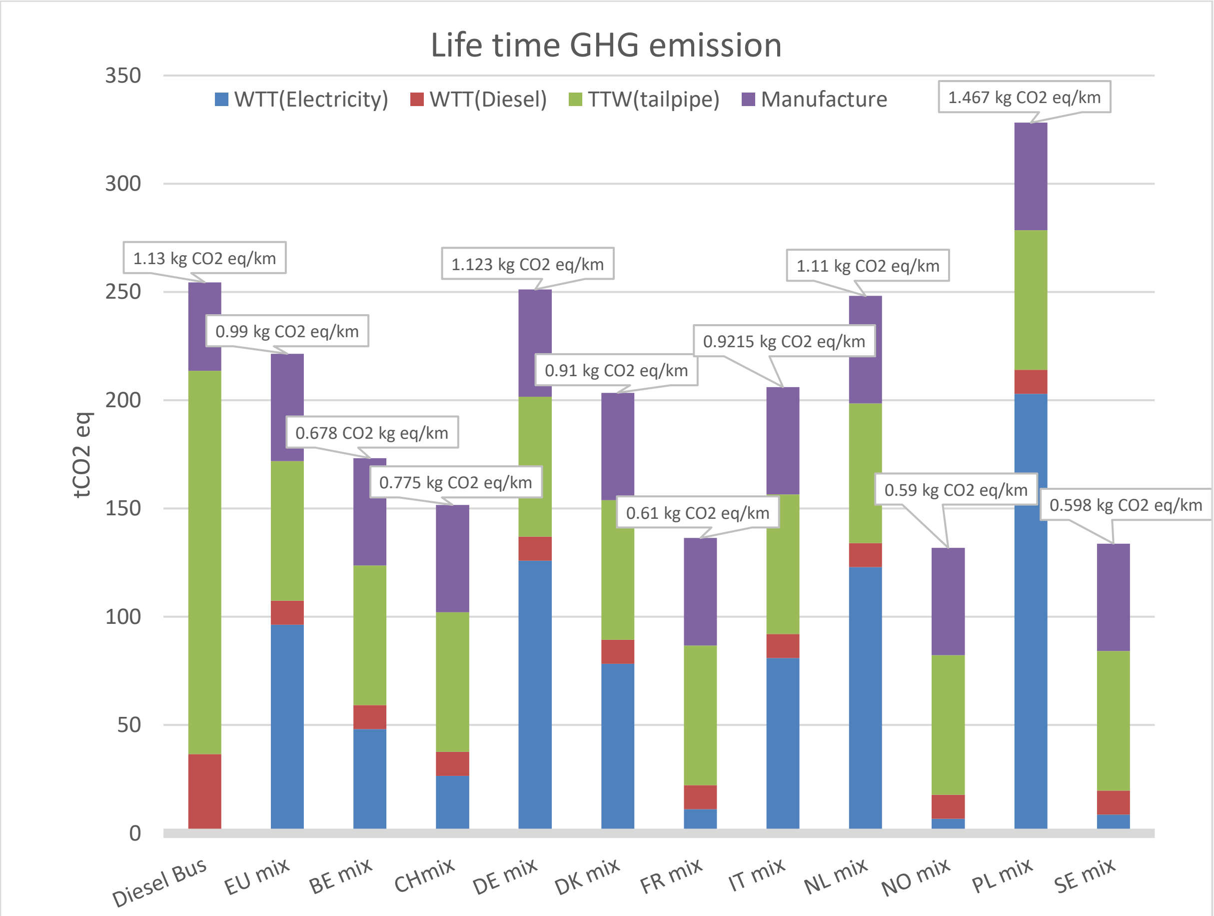

Figure 6: Life time GHG emission from different EU country electricity mix

For coal depending country like Poland, the plug-in hybrid bus actually perform worse than the diesel bus in terms of greenhouse gas emissions. It needs to be noted that all plug-in electric busses will improve local air quality when electricity is not generated within the low emission zone. For low carbon intense country, lifetime GHG emission goes as low below 0.59 kg CO_2 eq/km which is almost 48% reduction from diesel bus. Contrary to that, in Poland, the value is 1.47 kg CO_2 eq/km that is 29% higher than the diesel bus option.

6 Conclusion

From the life cycle perspective, it is seen that the plug-in heavy-duty vehicle performs well compared to diesel bus and can bring benefit to the environment provided that the electricity production is less carbon intensive. Also, from the literature study, the heavy-duty hybrid vehicles are also found to perform well compared to diesel alternative. The range of GHG emission rate for the hybrid heavy-duty vehicles are found to be in between 0.75 kg CO_2 eq/km to 1.45 kg CO_2 eq/km. Here in this manuscript, the heavy-duty vehicle is a plug-in hybrid and for 30km in the non-emission zone, it has the drive in pure electric mode. Therefore it requires a significant amount of electric energy for charging. In EU average mixed electricity context, which has carbon intensity of 0.483 kg CO_2 eq/kWh, the plug-in hybrid bus emits 0.99 kg CO2 eq/ km with considering manufacture related emission. Around 43% of total emission came from WTT emission of electricity production. If the vehicle can be charged with renewable alternative this emission could be avoided and can be reduced to 0.55 kg CO_2 eq/km. More improvement can be done while manufacturing the plug-in heavy-duty vehicle. For instance, using different battery technology and find out which technology is the most suitable for the heavy-duty vehicle and also environmentally efficient. Next step of this research will focus on this. The most environmental load while manufacturing the heavy-duty vehicle found on the production of the glider. Here again electricity consumption while manufacturing it, found out to be one of the major environmental loads. Therefore, clean electricity production and grid integration is the key to overall future clean electric transport.

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References

[1] H. Zhao, A. Burke, and M. Miller, "Analysis of Class 8 truck technologies for their fuel savings and economics," *Transp. Res. Part D Transp. Environ.*, vol. 23, pp. 55–63, Aug. 2013.

[2] "Reducing CO2 emissions from heavy-duty vehicles | Climate Action." [Online]. Available: https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en. [Accessed: 26-Oct-2018].

[3] Y. Wang, Y. Huang, J. Xu, and N. Barclay, "Optimal recharging scheduling for urban electric buses: A case study in Davis," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 100, pp. 115–132, Apr. 2017.

[4] "OUR PROJECT – OBJECTIVES." [Online]. Available: https://h2020-orca.eu/our-project/objectives/. [Accessed: 05-Apr-2019].

[5] C. M. Martinez, X. Hu, D. Cao, E. Velenis, B. Gao, and M. Wellers, "Energy Management in Plug-in Hybrid Electric Vehicles: Recent Progress and a Connected Vehicles Perspective," *IEEE Trans. Veh. Technol.*, vol. 66, no. 6, pp. 4534–4549, Jun. 2017.

[6] K. Jwa and O. Lim, "Comparative life cycle assessment of lithium-ion battery electric bus and Diesel bus from well to wheel," *Energy Procedia*, vol. 145, pp. 223–227, Jul. 2018.

[7] B. Sen, T. Ercan, and O. Tatari, "Does a battery-electric truck make a difference? – Life cycle emissions, costs, and externality analysis of alternative fuel-powered Class 8 heavy-duty trucks in the United States," *J. Clean. Prod.*, vol. 141, pp. 110–121, Jan. 2017.

[8] A. Lajunen, "Lifecycle costs and charging requirements of electric buses with different charging methods," *J. Clean. Prod.*, vol. 172, pp. 56–67, Jan. 2018.

[9] N. Wang, Z. Y. Gong, and J. Ma, "Hybrid Electric and Battery Electric City Buses Benefit Analysis Based on Lifecycle Cost and Emission," *Adv. Mater. Res.*, vol. 347–353, pp. 952–955, 2011.

[10] Q. Song *et al.*, "Could urban electric public bus really reduce the GHG emissions: A case study in Macau?," *J. Clean. Prod.*, vol. 172, pp. 2133–2142, Jan. 2018.

[11] R. Wang, Y. Wu, W. Ke, S. Zhang, B. Zhou, and J. Hao, "Can propulsion and fuel diversity for the bus fleet achieve the win–win strategy of energy conservation and environmental protection?," *Appl. Energy*, vol. 147, pp. 92–103, Jun. 2015.

[12] B. Zhou *et al.*, "Real-world performance of battery electric buses and their life-cycle benefits with respect to energy consumption and carbon dioxide emissions," *Energy*, vol. 96, pp. 603–613, Feb. 2016.

[13] M. El Hannach, P. Ahmadi, L. Guzman, S. Pickup, and E. Kjeang, "Life cycle assessment of hydrogen and diesel dual-fuel class 8 heavy duty trucks," *Int. J. Hydrogen Energy*, vol. 44, pp. 8575–8584, 2019.

[14] O. H. Maxime Wautrin, Dai-Duong Tran, Mohamed El Baghdadi, Joeri Van Mierlo, "Co-design Approach and Optimization for Plug-In Hybrid Buses 'Submitted to EVS32.,'" 2019.

[15] "ECOSTRALIS." [Online].Available:https://www.iveco.com/finland/collections/catalogues/Documents/tutti prodotti/ECOSTRALIS_CAT_ING.pdf. [Accessed: 10-Apr-2019].

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