ENVIRONMENTAL IMPACT MODELLING FOR A WESTERN BALKANS MOBILITY DEVELOPMENT SCENARIO BASED ON THE ELECTRICITY PRODUCTION ENERGY MIX

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Abstract. Electric vehicles (EVs) are predicted to be a major part of Europe's future mobility framework and the amount of electricity used by them, influenced by variations in the average driving habits, in conjunction with the local energy mix, will have a significant effect on the local GHG (Greenhouse gasses) emissions footprint. Seeing as the Western Balkans 6 (WB6) have been trailing behind larger Western European economies in terms of their electrical energy producing solutions, the level of life-cycle emissions from EVs in the WB6 will greatly depend on how the electricity used to recharge these vehicles per their normal function, is produced. Considering this, the purpose of this paper was to analyse the trend of increasing production of EVs and their proliferation in traffic in the WB6, and model their GHG emissions based on a proposed development scenario that takes from energy strategic planning in the WB6, in order to check if the tendency to use electricity to power cars rather than fossil fuels is entirely justified. The findings indicate a rate of growth for EVs share on the personal vehicle market by 2050, and an increase in their mileage, however with an insignificantly small rise to the total CO_2 emission of the LDV (light-duty vehicle) fleet, a disparity which is a consequence of the improved technology, greater share of biofuels in liquid and gaseous fuels and partial de-carbonisation of the energy sector in the WB6.

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AIMS AND BACKGROUND

According to the European Automobile Manufacturers Association, as of 2020, petrol and diesel vehicles account for the largest share of Europe's transport network[1]. However, causing major air pollution and leading to global warming[2,3] the European transport authorities have supported and enforced regulations that require the use of more fuel-efficient vehicles, vehicles using alternative fuels, hybrids or fully electric vehicles (EVs). In fact, governments have been lobbying for a ban on conventional internal combustion engine vehicles (ICEVs) by set times frames, looking to make a complete switch to EVs during this or the next decade[4]. The push for lower-emission vehicles, with the ultimate goal being a move to zero-emissions has resulted in modern EVs, as they produce no direct, tailpipe emissions such as smog-forming pollutants and greenhouse gasses (GHGs)[5].

With this major benefit in mind, the potential disadvantages of EVs lay with their life cycle emissions, which unlike tailpipe emissions, are related to fuel and vehicle production, processing, distribution, use, and recycling/disposal. Life cycle emissions account for a significant environmental impact in their own right and are especially important when talking about EVs as they are rarely thought of, mainly arise from the manufacturing cycle of these vehicles, as well as from the production of the electricity used to recharge them[6].

While it is pretty straightforward to calculate the amount of energy used to charge a vehicle's battery, things get complicated in comparing the impact of a battery charged by a natural-gas-fired power plant with one that's been charged using coal as fuel or even nu-clear power[7]. Different authors agree that although EVs will lead to lowering GHG emissions from the transportation sector, they will only play a substantially small part in the near future, while larger contributions can be expected in the decades to follow[8,9]. However, studies have also been quick to point out, that the energy sector presents itself as a major point of worry since the real carbon costs of EVs (among other challenges) rise from it[9]. With this in mind, the prediction and development of future mobility and environmental impact scenarios has been somewhat of a focal point for environmental researchers[10-12] with the focus being put on the increasing number of EVs in traffic and the potential changes in the electricity production energy mix.

Knowing that the Western Balkans 6 (WB6) have been trailing behind larger Western European economies in terms of the environmentally friendly, electrical energy producing solutions[13-17], the level of life cycle emissions from EVs in these countries will greatly depend on how the electricity used to recharge the vehicles per their normal function, is produced. Additionally, the amount of electricity used by EVs is also influenced by variations in the average driving habits in various geographic areas due to local climate conditions and traffic circumstances. This, in conjunction with the local energy mix, will have a significant effect on the local GHG emissions footprint and the air pollution effects caused by the local transport and energy sector. Seeing as none of the abovementioned related works focus strictly on the Western Balkans as a geographical region of interest, the purpose of this paper is to analyse the trend of increasing production of EVs and their proliferation in traffic in the Western Balkans, and model their GHG emissions based on a proposed development scenario, that takes from energy strategic planning in the WB6, in order to check if the tendency to use electricity to power cars rather than fossil fuels in the WB6 is entirely justified.

The countries of the Western Balkans 6: Serbia, Bosnia and Herzegovina, Montenegro, Albania, Republic of North Macedonia and Croatia, were part of the Yugoslavian unified energy system (excluding Albania) characterised with an energy-intensive economy, an unreliable power transmission system, a low level of gas and oil reserves, and diversification of sources of supply for these resources[13,14]. The high energy intensity in particular is a result of the unfavorable energy mix in the WB region dominated by a high share of fossil fuels in the supply mix (coal in particular) while the remainder consists of natural gas, oil, and a considerably smaller share of renewable energy sources. (Table 1) This data will be used to determine the CO_2 eq/km for the day to day operation of EVs within the WB6 boundaries.

Looking at Table 1, and the last five years of available data, which end in 2017, and with no other sources pointing on a change of this state, fossil fuels have a particularly high share in electricity generation in Bosnia and Herzegovina and in Serbia where they reach nearly 70%, with a slightly lower share in Republic of North Macedonia, Montenegro and Croatia, while Albania is completely reliant on its hydropower. Despite of the fact that this electricity generation mix plays a significant role in air pollution and environmental degradation, and prevents the fulfillment of commitments assumed by the WB6 under the Paris Agreement and the Energy Community membership, the WB countries continue to build or plan to build new coal-fired power plants[18,19].

Table 1. Western Balkans, Europe and World energy mix percentage in the production of electricity in 2017 (2021)

Energy Mix	Europe	World	Serbia	Bosnia and Herzegovina	Montenegro	Albania	North Macedonia	Croatia
Fossil	50.02	65.78	71.21	64.95	43.39	0	69.99	32.67
Wind	6.57	4.71	0.04	0.01	0.64	0	1.52	7.12
Solar	2.3	1.93	0.02	0.062	0	0.2	0.35	0.41
Hydro	17.21	16.82	28.72	34.99	55.97	99.98	28.15	59.8
Nuclear	23.58	10.42	0	0	0	0	0	0
Geothermal	0.32	0.33	0	0	0	0	0	0

This brings us to major negative implications in climate change and the amount of CO_2 that is emitted into the atmosphere, which adjusted for the size of the economy (measured through CO_2/GDP (PPP – Purchasing Power Parties), is up to three times the EU average. While it is difficult to reliably predict how many of these planned coal-fired power plants will be built, it is clear that the countries of the region, despite having energy strategies that prioritize the reduction of fossil fuel emissions and of electricity generation from fossil fuels, still view coal as a primary contributing factor to the sustainability of their power generation systems[20,21].

On a more favourable note, there are promising opportunities lying ahead regarding renewable energy sources, such as wind, solar, and sustainable biomass. Their technology related costs have come down dramatically and they can now present an important low-cost alternative to more traditional sources of energy. Not only are there untapped opportunities in this regard in the region, due to windy locations, sunny days and, in some countries, a large agriculture (and forestry) sector, but there is also increasing interest from foreign investors and financiers in renewable energy[17,18]. Additionally, an important new option that will help the Western Balkans transition to lower carbon energy sector is through the use of natural gas, which at the moment relies heavily on the construction of a Trans-Adriatic Pipeline (TAP) and the required supporting infrastructure.

EXPERIMENTAL

The VEWeBa (Vehicle Emissions in the Western Balkans) model developed for this research bases the growth of the number of vehicles in the countries of the Balkans in 2050 on the growth of the GPD, the (negative) population growth, vehicle penetration/GDP and on the number of vehicles per 1000 inhabitants in the EU countries with similar GDP to the WB6. (Table 2).

According to the Exxon Mobil Outlook for Energy 2014[18], the number of vehicles grows as the income (GDP per capita) rises in a country. Hence, it can be expected that the number of vehicles per capita in the WB countries will reach 490 by 2050, and the number of vehicles will grow from 5 933 828 to 10 035 385 which is a growth of 69.1%.

Table 2. Projected vehicle number growth in the WB6 in 2020/2050 according to the VEWeBa scenario

Country	Number of vehicles per 1000 inhabitants	Total number of vehicles in 2020	Estimated number of motor vehicles in 2050
Serbia	336	2 340 020	3 428 173
North Macedonia	194	403 316	1 039 474
Albania	167	481 114	1 440 461
Montenegro	326	202 322	310 309
Bosnia and Herzegovina	258	910 969	1 765 443
Croatia	389	1 596 087	2 051 525

The Global Transport Scenarios 2050 by the World Energy Council[19] state that there are two main directions of development of the automotive industry and hence of the light-duty vehicle (LDV) fleet. The market-driven scenario shows that the global car fleet will still be dominated by an 89% share for the conventional liquid fuel ICEV and ICE Hybrids while only 6% share is captured by electric, fuel cells, and plug-in vehicles. In the Regulation driven scenario the global car fleet in 2050 will be very diverse, with shares of 26% for liquid fuel conventional ICEV (19% petrol and 7% diesel); 26% for liquid hybrids (18% petrol and 8% diesel); 18% plug-ins; 16% electric; 8% gas vehicles; and 6% for others.

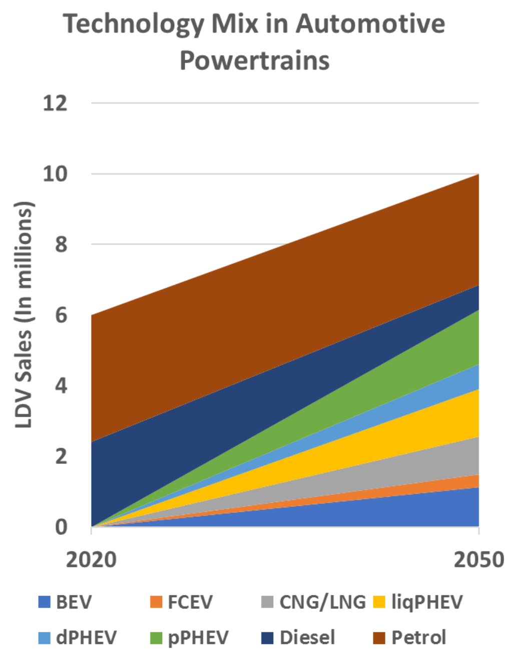

Fig. 1. Current (2020) and projected (2050) number of vehicles per 1000 inhabitants in the Western Balkans

Vehicle characteristics are largely determined by the desire of new-car buyers in wealthier countries, so there may be a 5-10 year lag before new technologies reach second-hand vehicle markets in large quantities, particularly through imports to many developing countries including the WB6 countries (though this situation will likely change in the coming decades as new car sales rise across non-OECD countries)[22]. Hence, the technology mix in Western Balkans Regulatory driven scenario for 2050 will be similar to the Organisation for Economic Co-operation and Development (OECD) regulatory driven scenario for 2040. The projected (2050) technology mix in LDVs for the WB6 countries is given in Fig. 1.

Although we will see a substantial rise in the number of LDVs over the next 30 years, due to improved engine fuel-combustion and improvements and changes in the fuel mix, (namely consuming more biofuels) the CO_2 emission factors of the 2050 vehicles, per individual vehicle will drop significantly.

Based on the abovementioned data regarding the current and projected electricity production energy mix, as well as the current and projected technology mix within the rising number of LDVs in the WB6, specifically for this research we developed the mathematical VEWeBa environmental impact model. The model is particularly intuitive as it factors in all uncertainties regarding the strategic planning in the energy sectors of the WB6 economies and both the positive and negative predictions that come with it. Most importantly, the model serves to provide us with a baseline value for better understanding the impact and implications of the carbon footprint in the years to come, 30 years into the future.

The total CO_2 emission $\boldsymbol{E_{WBtCO_2}}$ for the LDV fleet of the WB6 in 2050 can be calculated as a sum of the emissions of each separate country:

$$\boldsymbol{E_{WBtCO_2} = E_{MKD_{CO_2}} + E_{ALB_{CO_2}} + E_{SRB_{CO_2}} + E_{BIH_{CO_2}} + E_{MNG_{CO_2}} + E_{CRO_{CO_2}}} \quad (1)$$

This total amount of CO_2 emissions will be given in kt (CO_2)/year.

The amount of CO_2 emissions from the LDV fleets of the individual countries in this model are calculated as:

$$\boldsymbol{Ec_{CO_2} = \sum_{k=1}^{n} = N_k \cdot T_{LDV} \cdot ef_{CO_2 k} \cdot M_{2050} \cdot B_{beh}} \quad (2)$$

where $\boldsymbol{N_k}$ is the % of the LDV technology in the technology mix (where options in this model are: ICEV Petrol, ICEV Diesel, ICEV Petrol Hybrid, ICEV Diesel Hybrid, ICEV CNG/LNG, liquid fuel PHEV, Hydrogen FCEV and Battery-electric vehicle or BEV); $\boldsymbol{T_{LDV}}$ - the total number of light duty vehicles in the fleet; $\boldsymbol{ef_{CO_2 k}}$ - the CO_2 emission coefficient of the representative of the technology used (gCO_2/km); $\boldsymbol{M_{2050}}$ - the average mileage of a light duty vehicle in each country (km/year); $\boldsymbol{B_{beh}}$ - the coefficient of the improvement of the drivers behaviour in traffic.

And,

$$\boldsymbol{ef_{CO_2 i} = ef_{2020} \cdot t_{tech2050} \cdot f_{fuel2050} \cdot pf_{ev2050} + p_{pr2050}} \quad (3)$$

where $\boldsymbol{ef_{2020}}$ is the CO_2 emission factor of today's technology ancestor (emission factor in 2020) (-/-); $\boldsymbol{t_{tech2050}}$ - the coefficient of the possibility to improve the technology and the influence of the efficiency of the fuel (-/-); $\boldsymbol{f_{fuel2050}}$ - the factor of implementation of biofuel in a gaseous or liquid fuel (if B20 biodiesel mixture is modeled, the factor is 0,8). For the plug-in electric vehicles it is equal to 1. (-/-); $\boldsymbol{p_{pr2050}}$ - the CO_2 emission of the production of power unit (gCO_2/km); $\boldsymbol{pf_{ev2050}}$ - the factor that represents the primary fuel composition in the energy mix.

Finally,

$$\boldsymbol{pf_{ev2050} = \sum_{j=1}^{n} pf_{share\,j} \cdot t_{ef\,j} \cdot f_{ef\,j}} \quad (4)$$

where $\boldsymbol{pf_{share\,j}}$ is the percentage of primary fuel (or technology) in the electrical energy mix of the country. The model is using (j = Fossil, fossil CCPP – electricity and heat, hydro, solar and wind, waste to electricity, nuclear, biofuels to electricity); $\boldsymbol{t_{ef\,j}}$ -s the coefficient that represent the efficiency of the technology used for electricity production; $\boldsymbol{f_{ef\,j}}$ - the coefficient that represents CO_2 emission factor of the primary fuel.

RESULTS

The number of vehicles in the western Balkan countries in the period 2020 till 2050 is to raise for 69.1%, levelling to the vehicle penetration in OECD countries, due to improvement of the economic status of the citizens and the mileage of the average LDV will increase for 30%. Technology penetration in the WB6 will follow the trend of the technology mix in the OECD countries but due to the economic gap, the vehicle technology in large will lag for 5 to 10 years. Hence, in 2050, the Western Balkans technology mix for cars will be very similar to the OECD technology mix in 2040.

Today's conventional ICEV on average consumes 8l of fuel per 100km and produces about 195 g(CO2)/km[19]. By implementing advanced fuel combustion technologies, parameter control, dual fuel technology and traffic optimisation, fuel consumption in LDVs can be lowered by as much as 40%. Further improvements can be expected for PHEVs, BEVs and FCEVs, however it is important to mention that these vehicles will come with an increase in costs which can be expected due to the presence of these new technologies. Moreover, there is a similarly high potential (up to 40%) to lower fuel consumption by implementing combustion control and optimization technologies in ICE vehicles and ICE-hybrid vehicles. Additionally, a part of the fuel can be easily substituted by introducing a suitable biofuel in the petrol, diesel and CNG fueled vehicles.

In the VEWeBa model, which takes into account these technology improvements and a biofuel mixture, the average petrol/ethanol fueled ICEV will have an emission of 103 g(CO_2)/km, while a diesel/biodiesel ICEV LDV will emit 84 g CO_2/km and the ICEV-hybrids will have emissions of 81 g(CO_2)/km and 73g/km. BEVs and FCEVs efficiency in 2050 will also see an increase compared to 2020, but only slightly (of about 5-10%), however the CO_2 emissions from EV and FCEV can be expected to drop with the change of the energy mix in the production of electricity in the WB6. The VEWeBa model shows that the CO_2 emission from the WB6 in 2050 will be close to 380 g(CO_2)/kWh of produced electricity. Knowing this, the emission of a generic EV in the WB6 in 2050 will amount to 76 g(CO_2)/km from the energy mix for electricity production.

As a behaviour factor due to the improved standard and accessible technology it is modeled that the average LDV will increase its mileage (km/year) 1% per year. Knowing this, the LDV CO_2 emission in 2020 is calculated as 23418 kt(CO_2)/year. Using the assumptions of the VEWeBa model, the LDV fleet emission of CO_2 for the WB6 equals 23816 kt(CO_2)/year. Even though the number of km/year for LDVs in the WB6 will grow by 89%, the total CO_2 emission of the LDV fleet will rise only 1.7%. This disparity of the growth is a consequence of the improved technology, greater biofuels share in liquid and gaseous fuels and partial de-carbonization of the energy sector in the WB6.

DISCUSSION

EVs life-cycle environmental impact is difficult to gauge, and the consumption of electricity per the EV vehicle fleet and the nature of the energy mix is but a segment in the overall estimation of these vehicles' carbon footprint.

First, behaviour factors and local conditions and infrastructure can influence the market penetration of new technologies, such as: driving range anxiety for EVs, longer fueling time, etc. A significant improvement of efficiency of LDVs may be achievable by an 'integrated approach' that includes better traffic management, intelligent transport systems, and improved vehicle and road maintenance. Day/night recharging patterns and the location of public recharging systems could affect how much EVs are driven, when and where they are driven, and potentially their GHG emissions impacts.

Additionally, the batteries in EVs make up the largest portion of the vehicle's mass, and therefore manufacturers need to strike a balance by lightening the rest of the vehicle[23]. This requires most components to be as light as possible, which is achieved by using aluminum and carbon-fiber-reinforced polymers that often require a lot of energy to produce. The batteries' themselves are produced through an extremely energy intensive process and are rarely recycled (during 2017 only 5% of lithium-ion batteries were recycled in the EU)[24], while if disposed improperly, they can release toxic chemicals.

Moreover, permanent magnet motors used with EVs contain rare-earth metals that in-crease the power output of these motors, whose distribution in small quantities over different locations, makes their extraction environmentally unfriendly[25]. The mining and processing of lithium, copper, and nickel consumes a lot of energy, and in addition, especially in countries with weak legislation and/or enforcement thereof, mineral exploration may release toxic compounds in the surrounding area thereby exposing the population. Moreover, even when charged from renewable sources, such as solar energy, the associated environmental repercussions from manufacturing the huge number of photovoltaic cells is completely ignored. Solar cells contain heavy metals, and their manufacturing re-leases sulfur hexafluoride, a GHG with 23 000 times the global warming potential of CO_2[7].

To sum up, a complete analysis of the environmental impact would include all of the above-mentioned implications that constitute the manufacturing process of EVs. That being said, this paper is major step forward in that direction, while these implications make great points for future work.

CONCLUSIONS

In this point in time, promotion of EVs in the vehicle technology mix in the WB6 is justified only in Albania and to a lesser degree in Croatia. In the other countries of the region, the measure to promote usage of EVs can be explained with lower local pollutant emission (especially in the major urban areas) and lower oil import dependence of the country, but ultimately it will contribute to higher GHG emission due to the large portion of fossil fuels in the energy mix.

Following the more favorable strategies for energy development of the WB6 and hopefully a trend to decarbonize parts of the energy sectors, the energy mix in 2050 should allow promotion and implementation of subsidies for EVs that will contribute to lower GHG emissions than today and will improve the local air quality. The CO_2 emissions of the 2050 petrol, diesel and natural gas ICEV will drop significantly as a consequence of improved engine technologies, usage of waste energy (trough hybrid motors and other innovations) and higher biofuel percentage in the liquid and gaseous fuels offered to the consumer. However, it may be expected that the 2050 ICEV will have a higher price than to-day’s ICEV due to the improved technologies and regulatory restrictions.

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