EVALUATION OF EMISSION REDUCTION PERFORMANCE OF ELECTRIC VEHICLES UNDER VARIOUS CLIMATIC AND DRIVING CONDITIONS

Esin Tetik Kollugil, Istanbul Technical University, Department of Industrial Engineering, tetikes@itu.edu.tr
Kemal Sarica, Gebze Technical University, Department of Industrial Engineering, kemalsarica@gtu.edu.tr
Y. Ilker Topcu, Istanbul Technical University, Department of Industrial Engineering, topcuil@itu.edu.tr

Overview

Electric vehicles (EVs) are getting very popular, and several markets announced zero-emission vehicle sales targets and subsidies to facilitate the electrification of cars in the pathway to transition to Net Zero Emissions by 2050 (IEA, 2022). However, developing countries stand one step behind EVs due to the infrastructure requirements and high investment costs. In early 2023, the share of EVs corresponds to only 0.12% of the total passenger cars in Turkiye. The sales afterwards are expected to increase due to the announced tax incentive for the EVs and the production of a new Turkish EV startup release. The sales are predicted to double the number of EVs in 2023, and the charging investments are accelerating.

Considering an EV as an emission abatement technology requires generating fewer emissions than an internal combustion engine (ICE) alternative despite the zero tailpipe emissions. The factors determining EVs' contribution to emission reduction vary between countries. The electricity generation mix and the emission coefficient is the primary factor of EV-related emissions, especially in a country like Turkiye, where 67% of the electricity was generated from thermal power in 2021.

Additionally, the energy efficiency of EVs is affected by the cold weather due to battery performance and the required HVAC (heating, ventilation and air conditioning) use, which increases energy consumption and emissions. Therefore, local climatic conditions should also be considered for an emission evaluation at the beginning of the investment phase of vehicle electrification to design the policies. Traffic conditions, driving style, other weather conditions etc., are other factors that affect the energy consumption of vehicles.

The electricity emission factor, ambient temperature, and driving conditions are used to assess the spatial and temporal effects on the range and emissions of EVs. Then, the EV-related emissions are compared with conventional vehicle emissions under the same conditions to evaluate the emission reduction potential of the EVs in Turkiye. This study points to the convenient conditions for EVs as an emission abatement option.

Methods

The comparisons were made for four WLTP driving conditions, low, medium, high and extra high, which have the average speed with stops of 18.9 km/h, 39.3 km/h, 56.4 km/h, and 92 km/h, respectively. Low stands for city centre driving with frequent stops and delays, while medium, high and extra high represent suburban, rural and motorway driving conditions.

Four different cities, Antalya, Istanbul, Ankara and Erzurum, which have average annual temperatures in 2015-2020 of 18.3°C, 15.5°C, 12.3°C, and 5°C are selected for this analysis. Considering the hourly temperatures in these cities, WLTP cycles, and hourly average emission factors, the corresponding EV emissions are compared with the ICEV emissions by assuming that the charging load is uniformly distributed and EVs are used as charge-and-drive at the same time slice.

Citroen ë-C4 with a 50-kWh battery is compared with Citroen C4 diesel (97 kW engine power) and gasoline (96 kW engine power) vehicles. In each driving profile, the specific energy consumption of ICEVs is considered, and the increase in the energy consumption due to the A/C use for temperatures higher than 23°C (Weilenmann et al., 2005) is calculated.

For the EV, the range estimations announced by the producer correspond to speed levels between 30 km/h to 130 km/h and temperature values between -10°C to 35°C. Piece-wise linear functions are generated with a maximum of 3.3% and 1.3% error for the HVAC on and HVAC off cases for the given speed levels. And for other speed levels, interpolation of the neighbour function values is calculated. In EV consumption, grid-to-motor inefficiencies (Eberhard & Tarpenning, 2006) and transmission and distribution losses are also accounted for.

The hourly average electricity emission factor is calculated from the hourly electricity generation mix (EPIAS, n.d.). For fossil fuels, in addition to the direct CO_2 emission factors by fuel type (IPCC, 2006), GHG emissions from fuel extraction to the power plant (Turconi et al., 2013) are also considered. Average GHG emissions from Turconi's study, including infrastructure emissions, are utilized for renewable resources.

Results

EVs are invincible in the medium driving profile, which even though this is the second-best driving condition for the ICEVs in terms of energy consumption, the differences between the ICEV and EV emissions are at the highest level in any city's climatic conditions. Therefore, using EVs under medium speed driving profile has the highest emission abatement potential. In Istanbul and Antalya, the number of instances that EV emissions are higher than ICEV emissions corresponding to less than 5% of the analysis period. Moreover, C4 gasoline emissions are higher than ë-C4 all of the time in warm cities. In Ankara, this ratio is limited to 6%, and 15% of the time for EV comparisons with gasoline, and diesel vehicles, respectively.

The ë-C4 has the worst emission performance in the low-speed profile. In Erzurum, gasoline vehicle emissions are less than EV emissions 60% of the time, and diesel vehicle results are more dramatic. 80% of the time, EV cannot beat diesel vehicle, and the difference between the emissions reach the highest value on the benefit of the diesel vehicle. Within the analysis period, emissions emitted by ë-C4 are higher than gasoline-C4 at the low cycle only in Erzurum. However, the difference between the diesel-C4 is positive in all cities, implying that the diesel vehicle emits less CO_2 in city centre driving conditions.

On the other hand, the performance of the EV at high and extra high-speed profiles can be considered indifferent. In Erzurum, ë-C4 emissions are more than gasoline C4 emissions at around 34% of the time in both speed levels, and the ratio indicates 45% for diesel C4, as shown in Figure 1.

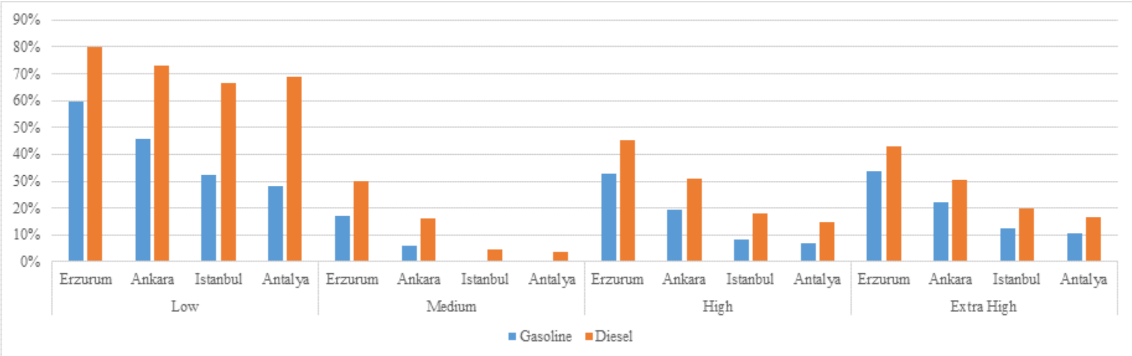

Figure 1 Share of the time EV emissions are higher than ICEV counterparts

Conclusions

EVs are not silver bullets for emission reduction targets. The current electricity generation mix, based heavily on thermal power plants, is a big obstacle for EVs as an emission reduction option. Therefore, supporting carbon-free electricity generation is a must. In the early phase of EV-related investments, the resources should be allocated for emission abatement coupled with detailed assessments, and the supporting policies should be designed accordingly. The subsidies should favour the use of EVs in mild climatic conditions (e.g. Istanbul and Antalya) in which offers the highest abatement potential. Since the medium driving profile is the most promising condition for emission reduction, suburban driving should be the target for EV penetration. Even though cold climate coupled with rural and motorway driving conditions is expected to be a big problem for EVs it is seen that city centre driving conditions under harsh climate conditions (e.g. Erzurum) is the worst at all. For city centre driving conditions, neither EVs nor ICEVs are good abatement options, but the comfortable mass transit infrastructure. Independent of the season and climatic conditions, daytime driving supports the emissions abatement. Different EV technologies may result in different outcomes and may require further studies.

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