2022-01-1127 Published 30 Aug 2022

Evaluating the Energy Consumption of an Electric Vehicle Under Real-World Driving Conditions

Yazan Al-Wreikat and Jose Ricardo Sodre Aston Univ

Citation: Al-Wreikat, Y. and Sodre, J.R., "Evaluating the Energy Consumption of an Electric Vehicle Under Real-World Driving Conditions," SAE Technical Paper 2022-01-1127, 2022, doi:10.4271/2022-01-1127.

Received: 14 Apr 2022 Revised: 24 May 2022 Accepted: 24 Jun 2022

Abstract

This investigation evaluates the energy consumption of an electric vehicle (EV) and identifies key factors that affect its energy efficiency, based on real-world operation for a range of driving characteristics and climate conditions over nearly four years in the streets of the second-largest UK city. The driving modes investigated were acceleration, deceleration, idling and cruise, determined by dividing each individual trip into kinematic segments based on vehicle speed and acceleration calculated second by second. From the results obtained, the EV energy consumption is directly influenced by changes in ambient temperature outside, largely due to the corresponding loads required from the use of auxiliary systems, mainly heating and air conditioning. An increase in trip idling events directly translates to a rise in EV energy consumption, while opposite outcomes were produced during cruising state with decreasing energy consumption. During the periods of high traffic on weekdays, the energy consumption is increased by nearly 15% as a direct impact of the increase in the number of stops, as the auxiliaries still require energy while the vehicle is at idle. The difference in energy consumption between weekday and weekend driving occurs mainly during heavy traffic periods, increasing by 20% on weekdays, primarily due to the rise in the number of stops for weekday driving. The results also show that the EV specific energy consumption varies each month, reaching a 55% increase from summer of least energy consumption to winter with the most requires energy, mainly due to large average ambient temperature changes.

Introduction

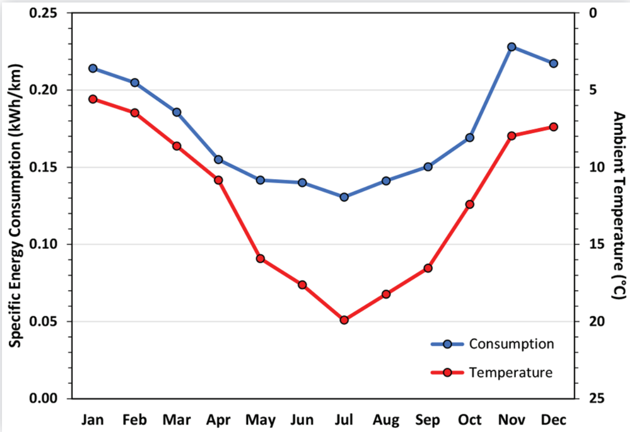
The transportation sector is the largest contributor to greenhouse gas (GHG) emissions, and vehicles exhaust emissions are the primary source of air pollution, particularly in dense populations [1]. In 2040, the number of passenger vehicles is expected to double, reaching 2 billion vehicles worldwide, and without alternatives to fossil fuels as an energy source, it will eventually lead to an increase in transportation sector emissions share [2]. One of the solutions to decarbonise the transport sector is to shift from internal combustion engine (ICE) vehicles to electric vehicles (EVs) [3]. Therefore, several governing bodies have developed strategies to reduce transportation sector GHG emissions through a set of targets, incentives and purchasing subsidies [4].

While EVs have many advantages, some limitations withheld their mass adoption. For example, range anxiety is perhaps the main obstacle for accepting EVs in the market [5]. A survey in the United Kingdom (UK) identified concerns about the impact of driving behaviour and the use of vehicle features on the range as one of several barriers to increasing the uptake of EVs [6]. These limitations are directly related to the energy consumption of EVs and highlight the importance of a better understanding of factors that influence their range.

The analysis of real-world data from EVs offers valuable information for the development of electric powertrain optimisation models [7] and prediction methods [8] to improve efficiency and provide solutions to reduce energy consumption and costs. Furthermore, the anticipated increase in EVs requires optimising charging infrastructure through foresee charging demand and requirements [9]. Analysis of EV driving behaviour alongside charging patterns provides valuable information on the development of charging infrastructure in small and medium-sized cities [10].

Several studies covered the impact of traffic, driving style, route and elevation on energy consumption but these studies primarily focused on ICE vehicles [11]. However, traditional driving cycles might not be adequate to evaluate and improve EVs as they have been developed based on conventional vehicles driving characteristics, which are considered different from EVs [12]. The estimated EV driving range from six legislative driving cycles differs by 20% to 38% compared to the one obtained from a constructed urban driving cycle for a city in China based on actual driving data [13]. Data from real-world driving tests of EV in India showed that energy consumption is higher than the dynamometer laboratory test by 42 to 90% affected by changes in traffic congestion

FIGURE 8 Monthly specific energy consumption and ambient temperature.



to a 55% increase from summer (June, July and August) to winter (December, January and February) months. The methodology here employed can be applied in future studies to evaluate the SEC of HEV, especially plug-in hybrid electric vehicles (PHEV), which larger batteries allow driving in electric mode for longer periods.

Factors Correlation

Figure 9 shows the correlation coefficient matrix between different factors determined using the Pearson correlation coefficient (PCC) method. The more intense the colour, the higher the correlation between the two variables. The PCC ranges from -1 to 1, a value equal to zero indicates no correlation, while the higher the absolute value, the stronger the correlation between the two factors [27]. The strong positive correlations between distance, average speed and cruising state show that cruising events increases with longer trips. These trips would typically have a higher percentage of motorway driving, as indicated by the increase in average speed with an increase in trip distance.

The correlation between the four driving states in the lower-left corner shows a high correlation between acceleration and deceleration states, while the cruising state only correlates with the idling state. Unlike the other states, the Idling state has a high correlation with all other states emphasizing the high influence of idling as previously discussed, which indicates that the idling state would be a good representative to measure the impact of driving mode on SEC. The negative correlation between average speed and stops per km or idling state highlights the traffic behaviour during rush hours as trips with high idling events (repeated stops with long idling periods) will increase the trip duration, decreasing the calculated average speed.

FIGURE 9 Pearson correlation coefficient matrix.

	Distance	Ambient Temperature	Average Speed	Stops Per km	Acceleration State	Deceleration State	Idle State	Cruising State
Distance	1.00	-0.01	0.73	-0.30	-0.06	-0.23	-0.33	0.65
Ambient Temperature	-0.01	1.00	0.03	0.03	0.09	0.13	-0.12	0.05
Average Speed	0.73	0.03	1.00	-0.57	0.19	0.11	-0.68	0.81
Stops Per km	-0.30	0.03	-0.57	1.00	-0.19	-0.16	0.44	-0.43
Acceleration State	-0.06	0.09	0.19	-0.19	1.00	0.77	-0.71	-0.01
Deceleration State	-0.23	0.13	0.11	-0.16	0.77	1.00	-0.66	-0.09
Idle State	-0.33	-0.12	-0.68	0.44	-0.71	-0.66	1.00	-0.65
Cruising State	0.65	0.05	0.81	-0.43	-0.01	-0.09	-0.65	1.00

Conclusions

The energy consumption of an EV was evaluated using real-world driving data collected in Birmingham, one of the UK's largest cities. In general, the highest variation and highest values of specific energy consumption were observed for short trips. The difference in energy consumption between weekday and weekend driving occurs mainly in heavy traffic periods, primarily due to the increased number of stops. Depending on the use of auxiliaries, the number of stops and idling state share in a trip can significantly influence the specific energy consumption. From the factors investigated, ambient temperature outside alongside trips with a large share of idling events has the highest impact on the SEC of an EV depending on the increase of load from auxiliaries. Months with moderate temperature showed a small variation in specific energy consumption, while months with an average temperature below 15°C showed a significant increase in energy consumption, which is linked to the use of auxiliaries. The increase in specific energy consumption reaches 55% from the summer to winter.

References

1. Li, Z., Khajepour A. and Song J., "A Comprehensive Review of the Key Technologies for Pure Electric Vehicles," *Energy* 182:824-839, 2019, https://doi.org/10.1016/j.energy.2019.06.077.
2. Held, M. and Schücking M., "Utilization Effects on Battery Electric Vehicle Life-Cycle Assessment: A Case-Driven Analysis of Two Commercial Mobility Applications," *Transportation Research Part D: Transport and Environment* 75:87-105, 2019, https://doi.org/10.1016/j.trd.2019.08.005.
3. Hill, G., Heidrich O., Creutzig F. and Blythe P., "The Role of Electric Vehicles in Near-Term Mitigation Pathways and Achieving the UK's Carbon Budget," *Applied Energy* 251:113111, 2019, https://doi.org/10.1016/j.apenergy.2019.04.107.
4. Biresselioglu, M.E., Demirbag Kaplan, M., and Yilmaz, B.K., "Electric Mobility in Europe: A Comprehensive Review of Motivators and Barriers in Decision Making Processes," *Transportation Research Part A: Policy and Practice* 109 (2018): 1-13, https://doi.org/10.1016/j.tra.2018.01.017.

5. Mahmoudzadeh Andwari, A., Pesiridis, A., Rajoo, S., Martinez-Botas, R. et al., “A review of Battery Electric Vehicle technology and readiness levels,” *Renewable and Sustainable Energy Reviews* 78 (2017): 414-430, https://doi.org/10.1016/j.rser.2017.03.138.
6. Berkeley, N., Jarvis, D., and Jones, A., “Analysing the Take up of Battery Electric Vehicles: An Investigation of Barriers Amongst Drivers in the UK,” *Transportation Research Part D: Transport and Environment* 63 (2018): 466-481, https://doi.org/10.1016/j.trd.2018.06.016.
7. Zhu, D., Pritchard, E., Dadam, S.R., Kumar, V. et al., “Optimization of Rule-Based Energy Management Strategies for Hybrid Vehicles Using Dynamic Programming,” *Combustion Engines* 184, no. 1 (2021): 3-10, http://doi.org/10.19206/CE-131967.
8. Alqahtani, M., Scott M.J. and Hu M., “Dynamic Energy Scheduling and Routing of a Large Fleet of Electric Vehicles Using Multi-Agent Reinforcement Learning,” *Computers & Industrial Engineering* 169:108180, 2022, https://doi.org/10.1016/j.cie.2022.108180.
9. Mourad, A. and Hennebel M., “The Optimal Deployment of Recharging Stations for Electric Vehicles Based on Mobility Flows and Electric Grid Specifications,” presented at *2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe) 2020*, 26-28 Oct. 2020, https://doi.org/10.1109/ISGT-Europe47291.2020.9248874.
10. Weldon, P., Morrissey, P., Brady, J., and O’Mahony, M., “An Investigation Into Usage Patterns of Electric Vehicles in Ireland,” *Transportation Research Part D: Transport and Environment* 43 (2016): 207-225, https://doi.org/10.1016/j.trd.2015.12.013.
11. Vepsäläinen, J., Kivekäs K., Otto K., Lajunen A., et al., “Development and Validation of Energy Demand Uncertainty Model for Electric City Buses,” *Transportation Research Part D: Transport and Environment* 63:347-361, 2018, https://doi.org/10.1016/j.trd.2018.06.004.
12. Gong, H., Zou Y., Yang Q., Fan J., et al., “Generation of a Driving Cycle for Battery Electric Vehicles: A Case Study of Beijing,” *Energy* 150:901-912, 2018, https://doi.org/10.1016/j.energy.2018.02.092.
13. Zhao, X., Ma J., Wang S., Ye Y., et al., “Developing an Electric Vehicle Urban Driving Cycle to Study Differences In Energy Consumption,” *Environmental Science and Pollution Research* 26(14):13839-13853, 2019, https://doi.org/10.1007/s11356-018-3541-6.
14. Lairenlakpam, R., Kumar, P., and Thakre, G., “Effect of Real-World Driving and Drive Modes on Electric Vehicle Energy Consumption and Performance in a Tier-II Indian City,” *SAE International Journal of Sustainable Transportation, Energy, Environment, & Policy* 1, no. 13-01-02-0008 (2020): 127-143, https://doi.org/10.4271/13-01-02-0008.
15. Mansour, C., Haddad M. and Zgheib E., “Assessing Consumption, Emissions and Costs of Electrified Vehicles Under Real Driving Conditions in a Developing Country with an Inadequate Road Transport System,” *Transportation Research Part D: Transport and Environment* 63:498-513, 2018, https://doi.org/10.1016/j.trd.2018.06.012.
16. Du, G., Cao, W., Hu, S., Lin, Z. et al., “Design and Assessment of an Electric Vehicle Powertrain Model Based on Real-World Driving and Charging Cycles,” *IEEE Transactions on Vehicular Technology* 68, no. 2 (2019): 1178-1187, https://doi.org/10.1109/TVT.2018.2884812.
17. Zhang, J., Wang, Z., Liu, P., and Zhang, Z., “Energy Consumption Analysis and Prediction of Electric Vehicles Based on Real-World Driving Data,” *Applied Energy* 275 (2020): 115408, https://doi.org/10.1016/j.apenergy.2020.115408.
18. Client Earth, “UK Air Pollution: How Clean is the Air You Breathe?,” 2020, accessed: 14 May 2021. https://www.clientearth.org/latest/latest-updates/news/uk-air-pollution-how-clean-is-the-air-you-breathe/#:~:text=The%20UK%20is%20failing%20to,breaching%20the%20EU%20legal%20limits.
19. Sentoff, K.M., Aultman-Hall L. and Holmén B.A., “Implications of Driving Style and Road Grade for Accurate Vehicle Activity Data and Emissions Estimates,” *Transportation Research Part D: Transport and Environment* 35:175-188, 2015, https://doi.org/10.1016/j.trd.2014.11.021.
20. Bishop, J.D.K., Axon, C.J., and McCulloch, M.D., “A Robust, Data-Driven Methodology for Real-World Driving Cycle Development,” *Transportation Research Part D: Transport and Environment* 17, no. 5 (2012): 389-397, https://doi.org/10.1016/j.trd.2012.03.003.
21. Yang, Y., Li T., Hu H., Zhang T., et al., “Development and Emissions Performance Analysis of Local Driving Cycle for Small-Sized Passenger Cars in Nanjing, China,” *Atmospheric Pollution Research* 10(5):1514-1523, 2019, https://doi.org/10.1016/j.apr.2019.04.009.
22. DfT, “Road traffic estimates in Great Britain: 2019,” UK Government, 2020, accessed: 11 April 2022. https://www.gov.uk/government/statistics/road-traffic-estimates-in-great-britain-2019.
23. Hao, X., Wang, H., Lin, Z., and Ouyang, M., “Seasonal Effects on Electric Vehicle Energy Consumption and Driving Range: A Case Study on Personal, Taxi, and Ridesharing Vehicles,” *Journal of Cleaner Production* 249 (2020): 119403, https://doi.org/10.1016/j.jclepro.2019.119403.
24. Kumar, V., Zhu, D., and Dadam, S.R., “Intelligent Auxiliary Battery Control-A Connected Approach,” SAE Technical Paper 2021-01-1248, 2021, https://doi-org.imeche.idm.oclc.org/10.4271/2021-01-1248.
25. Hayes, J.G. and Davis K., “Simplified Electric Vehicle Powertrain Model for Range and Energy Consumption Based on EPA Coast-Down Parameters and Test Validation by Argonne National Lab Data on the Nissan Leaf,” presented at *2014 IEEE Transportation Electrification Conference and Expo (ITEC)* 2014, 15-18 June 2014, https://doi.org/10.1109/ITEC.2014.6861831.
26. Donkers, A., Yang, D., and Viktorović, M., “Influence of driving Style, Infrastructure, Weather and Traffic on Electric Vehicle Performance,” *Transportation Research Part D: Transport and Environment* 88 (2020): 102569, https://doi.org/10.1016/j.trd.2020.102569.
27. Wang, Y., Li, W., Zhang, Z., Shi, J. et al., “Performance Evaluation and Prediction for Electric Vehicle Heat Pump Using Machine Learning Method,” *Applied Thermal Engineering* 159 (2019): 113901, https://doi.org/10.1016/j.applthermaleng.2019.113901.