

Forecasting the Utilization Efficiency of Electric Transport Vehicles in Hot Climate Conditions

Ollanazarov Xushnudbek Fayzullo oğlu¹, Fayzullo Ollanazarovich Xujayev²

^{1,2}New Uzbekistan University
 Email: fayzullo.khujaev@gmail.com

ARTICLE INFO

Keywords:

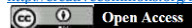
electric transport vehicle,
 electric vehicle,
 electric bus,
 hot climate, battery, SOC,
 energy consumption,
 air conditioning,
 operational efficiency,
 forecasting, EMS, V2G.

Vol.01, No.04, 2026

<https://doi.org/10.5281/zenodo.22938234>

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CCBY4.0).

<http://creativecommons.org/licenses/by/4.0/>



ABSTRACT

This article analyzes the main factors affecting the utilization efficiency of electric transport vehicles in hot climate conditions and the issues of forecasting their performance. The operational efficiency of electric transport vehicles is closely related to ambient air temperature, battery state of charge (SOC), driving speed, road conditions, vehicle load level, as well as the energy consumption of air conditioning and other auxiliary electrical systems. A review of the literature shows that under high-temperature conditions, the energy consumed for battery thermal management and passenger compartment cooling can account for a significant share of the vehicle's total energy consumption. Therefore, assessing the actual operational efficiency of electric transport vehicles solely on the basis of nominal battery capacity or the driving range specified by the manufacturer is insufficient. The article considers physical, statistical, and machine learning approaches to forecasting the energy consumption of electric transport vehicles and proposes a multifactor forecasting model for hot climate conditions. In addition, the possibilities of energy management systems (EMS), vehicle-to-grid (V2G) technology, and the application of end-of-life batteries in secondary energy storage systems are considered. The research results demonstrate the need for an integrated approach to the advance assessment of energy consumption, charging requirements, and operational efficiency of electric buses and electric vehicles under Central Asian conditions.

Introduction

Reducing dependence on fossil fuels in the transport sector, improving energy efficiency, and reducing the amount of harmful substances emitted into the atmosphere are among the important factors driving the expansion of the use of electric transport vehicles. In recent years, the global market share of electric vehicles, electric buses, and other electric transport vehicles has been increasing significantly. According to data from the International Energy Agency, global electric car sales exceeded 20 million units in 2025, accounting for approximately one-quarter of new car sales. At the same time, the total electricity consumption of electric transport vehicles is also increasing.

The development of electric transport vehicles is not limited to cars, but also includes the expanding use of electric buses in urban public transport. In 2024, global sales of medium- and large-capacity electric buses exceeded 70,000 units. This indicates a trend toward making electric buses an important element of urban transport systems. However, the practical operational efficiency of an electric transport vehicle may differ significantly from the nominal technical specifications provided by the manufacturer. This is influenced by ambient air temperature, road conditions, driving speed, the number of accelerations and decelerations, vehicle load level, road gradient, battery state of charge, and auxiliary electrical systems, particularly the operation of the air conditioning system. In modern studies, forecasting the energy consumption of electric transport vehicles under real operating conditions is considered an important issue for optimizing transport routes, planning charging infrastructure, and managing vehicles.

This issue is particularly relevant in regions with hot climates. Under high ambient temperature conditions, a dual effect on the energy consumption of electric transport vehicles is observed. On the one hand, the energy demand of the cooling system increases to maintain the battery thermal condition within the required range. On the other hand, the use of an air conditioning system is necessary to ensure a comfortable microclimate in the passenger compartment. Since air conditioning in electric transport vehicles uses electricity directly, its operation can affect the driving range.

Studies published in 2025 have shown the need to consider HVAC systems, temperature-dependent battery losses, and transport conditions together when assessing the energy consumption of electric buses under hot climate conditions. The study noted that under extreme temperature conditions, HVAC energy consumption can reach approximately 24% of the total energy demand, while temperature-related battery losses can contribute up to 12% of the total energy consumption.

Therefore, forecasting the efficiency of electric transport vehicles under hot climate conditions requires considering not only battery capacity and driving range, but also ambient temperature, air conditioning load, driving conditions, and the technical condition of the battery simultaneously.

Research objective — to systematize the main factors affecting the operational efficiency of electric transport vehicles under hot climate conditions and to develop a forecasting approach based on the relationships among ambient air temperature, energy consumption, battery state of charge, transport load, and auxiliary systems.

Literature review on the topic

Research on modeling and forecasting the energy consumption of electric transport vehicles can be conditionally divided into three main groups: physical models, statistical/regression models, and data-driven machine learning models.

Physical models take into account factors such as vehicle mass, aerodynamic drag, rolling resistance, acceleration, road gradient, electric motor efficiency, and regenerative braking. The advantage of this approach is the ability to explain the physical processes of the vehicle. However, due to the large number of variables present under real urban conditions, model calibration and the processing of large amounts of data are required.

Statistical and regression models make it possible to estimate energy consumption based on observed data. Although they are relatively simple and practical, they may be limited in representing complex nonlinear relationships.

In recent years, the use of machine learning methods for forecasting the energy consumption of electric transport vehicles has been increasingly expanding. A review study published in 2024 systematically analyzed, in addition to conventional vehicle dynamics models, regression, explainable machine learning, and neural network-based methods. The authors emphasize that accurate energy consumption forecasting is important for route optimization, charging infrastructure planning, and real-time vehicle management.

Studies focusing on the temperature factor show that the driving range and energy consumption of electric transport vehicles are sensitive to ambient temperature. A 2025 study considered the temperature dependence of the battery's available energy, powertrain, and HVAC load jointly.

In addition, experiments under real-world conditions demonstrate the need to consider ambient temperature as a separate variable when assessing energy efficiency. For example, a study investigating real-world driving conditions found that the operation of the HVAC system increased battery energy consumption under summer conditions.

The literature review shows that although the scientific basis for forecasting the energy consumption of electric transport vehicles is well developed, considering temperature + HVAC + battery

thermal condition + driving conditions + vehicle load within a single model under hot climate conditions remains an important practical research direction.

Research methodology

This article is of a review-analytical nature, and scientific literature related to the assessment and forecasting of the operational efficiency of electric transport vehicles under hot climate conditions was systematically analyzed.

The research methodology is based on the following sequence:

- identifying the operational performance indicators of electric transport vehicles;
- analyzing the impact of hot climate conditions on the battery and auxiliary systems;
- identifying the main variables affecting energy consumption;
- systematizing existing forecasting methods;
- developing a multifactor model for assessing the energy consumption and efficiency of electric transport vehicles;
- assessing the potential of EMS, V2G, and the use of secondary batteries.

The total energy consumption of an electric transport vehicle can be expressed in simplified form as:

$$[E_{total} = E_{tr} + E_{HVAC} + E_{BTM} + E_{aux}]$$

where:

E_{total} — total energy consumption;

E_{tr} — energy consumed for propulsion;

E_{HVAC} — energy consumed by heating, ventilation, and air conditioning systems;

E_{BTM} — energy consumed for battery thermal management;

E_{aux} — energy consumption of other auxiliary systems.

Under hot climate conditions, the dependence of energy consumption on temperature can be expressed by the following general function:

$$[E = f(T, V, SOC, L, P, H)]$$

where:

T — ambient air temperature;

V — average driving speed;

SOC — battery state of charge;

L — distance traveled;

P — vehicle load level;

H — energy demand of the HVAC system.

The practical distance that a vehicle can travel on a single charge can be estimated as:

$$[R = E_{usable} / e_{km}]$$

where:

E_{usable} — usable battery energy,

e_{km} — average energy consumption per kilometer.

This approach makes it possible to account for real operating conditions, unlike the nominal driving range specified by the manufacturer.

Analysis and results

Impact of Hot Climate on the Efficiency of Electric Transport Vehicles

The efficiency of an electric transport vehicle is not determined solely by the efficiency of the electric motor. Under high-temperature conditions, the interaction between the battery, inverter, electric motor, air conditioning system, and thermal management systems becomes more pronounced.

The main challenge in hot climates is maintaining the battery within its optimal temperature range. An increase in temperature places an additional load on the battery cooling system. If thermal management is insufficient, it may negatively affect the battery's power delivery characteristics, efficiency, and long-term performance. Modern studies identify thermal management as one of the key technical issues in the operation of electric transport vehicles under both hot and cold conditions.

Therefore, when assessing vehicle efficiency under high-temperature conditions, it is appropriate to consider not only battery capacity but also usable battery energy.

Battery State of Charge and Thermal Management

SOC is one of the key indicators in determining the operational efficiency of an electric transport vehicle. SOC represents the ratio of the energy available in the battery to its total usable capacity.

$$[\text{SOC} = (E_{\text{available}} / E_{\text{capacity}}) \times 100\%]$$

During vehicle operation, SOC decreases, while it increases during charging or regenerative braking.

Under hot climate conditions, SOC dynamics should be analyzed together with ambient temperature. High temperatures result in additional energy consumption for battery cooling. In addition, temperature, charging regime, and the number of cycles are important factors in the long-term operation of the battery.

Therefore, in the forecasting model, it is appropriate to consider SOC not only as an initial parameter but also as a time-varying indicator.

Impact of the Air Conditioning System on Energy Consumption

One of the specific characteristics of electric transport vehicles under hot climate conditions is the share of the air conditioning system in energy consumption.

In vehicles with internal combustion engines, the air conditioning compressor may operate partially using engine power. In electric transport vehicles, however, the cooling system uses electricity directly. Therefore, during periods of high ambient temperature, continuous operation of the air conditioning system may increase the amount of energy drawn from the battery.

This is particularly important for electric buses. A large number of passengers, frequent opening and closing of doors, solar radiation, and the large passenger compartment volume may increase the cooling load.

A study conducted in 2025 on the modeling of electric buses under hot climate conditions found that HVAC energy consumption accounted for a significant portion of the total energy demand under extreme temperature conditions.

Therefore, the following relationship can be considered separately in energy consumption forecasting for hot climates:

$$[E_{\text{HVAC}} = f(T, T_{\text{set}}, Q_{\text{solar}}, N_p, t)]$$

where:

T — ambient temperature,

T_{set} — set temperature for the passenger compartment,

Q_{solar} — effect of solar radiation,

N_p — number of passengers,

t — air conditioning operating time.

Impact of Driving Conditions and Transport Load

The energy consumption of an electric transport vehicle depends on driving speed, acceleration and braking frequency, road gradient, and vehicle mass.

In urban conditions, frequent stopping and restarting may increase energy consumption. Regenerative braking makes it possible to recover part of these losses; however, it cannot always recover all of the energy lost during braking.

In electric buses, the number of passengers is also an important factor. An increase in passenger load increases the mass of the vehicle and consequently increases the amount of energy required for propulsion.

Therefore, considering only temperature in the forecasting model is insufficient. At least the following parameters should be included in the model:

Factor	Impact on Forecast
Ambient temperature	Changes battery and HVAC load
Average speed	Affects propulsion energy
Acceleration/braking	Changes urban energy consumption
Passenger load	Increases vehicle mass
Road gradient	Increases propulsion energy
SOC	Determines available energy
HVAC operation	Causes additional electricity consumption
Route length	Determines total energy demand
Travel time	Changes the effects of temperature and congestion

Forecasting Energy Consumption of Electric Transport Vehicles

Forecasting can be organized at three levels.

First level — physical model.

In this approach, energy consumption is calculated based on vehicle mass, speed, aerodynamic resistance, road gradient, and electric motor efficiency.

Second level — statistical model.

Regression equations are constructed based on historical data:

$$[E = a + b_1T + b_2V + b_3P + b_4SOC + b_5H + \varepsilon]$$

where:

a — constant coefficient,

b_i — model coefficients,

ε — random error.

Third level — machine learning model.

When large amounts of real-world operational data are available, algorithms such as Random Forest, Gradient Boosting, XGBoost, Support Vector Regression, and LSTM can be used. Recent review studies demonstrate the ability of machine learning methods to identify complex nonlinear relationships in forecasting the energy consumption of electric transport vehicles.

The following data can be incorporated into the model:

Meteorological data:

- air temperature;
- humidity;
- solar radiation;
- wind speed.

Transport data:

- speed;
- acceleration;
- route length;

- traffic congestion;
- road gradient.

Battery data:

- SOC;
- SOH;
- battery temperature;
- charging history.

Operational data:

- number of passengers;
- air conditioning operating status;
- travel time;
- number of stops.

Such a multifactor model makes it possible to determine in advance the amount of energy required by an electric transport vehicle for the upcoming route.

Use of EMS, V2G, and Secondary Batteries

The large-scale adoption of electric transport vehicles creates a new type of electricity demand. If many vehicles are charged simultaneously, the load on the electricity grid may increase. Therefore, energy management systems (EMS) that control the charging process are of significant importance.

EMS can manage energy flows between electric transport vehicles, buildings, photovoltaic installations, energy storage systems, and the electricity grid. In this case, historical consumption data and weather forecasts can be used to estimate energy demand for the subsequent time interval in advance.

The CEMS concept presented in the source provided by you implies precisely such an integrated approach. CEMS can exchange data with building energy management systems (BEMS), home energy management systems (HEMS), and facility energy management systems (FEMS) to manage the overall energy balance.

V2G technology makes it possible to consider an electric transport vehicle not only as an energy consumer but also, under certain conditions, as a resource capable of returning energy to the electricity grid. In such a system, electric transport vehicles can be used to balance grid loads, mitigate the variability of renewable energy sources, and provide certain ancillary services. Modern reviews of V2G identify battery degradation and control issues, along with its technical capabilities, as important limitations.

The simplified energy balance for V2G can be expressed as follows:

$$[P_{grid} = P_{load} - P_{EV} + P_{EV,dis}]$$

where:

P_{grid} — power drawn from the grid;

P_{load} — total load;

P_{EV} — EV charging power;

$P_{EV,dis}$ — power returned from EVs to the grid.

In this case, the primary function of the vehicle — transportation — should take precedence. Therefore, ensuring the minimum SOC condition:

$$[SOC \geq SOC_{min}]$$

is important in V2G management.

Another important aspect of the V2G system is the additional charging and discharging cycles of the battery. Scientific studies show that the impact of V2G on battery degradation depends on the type of service, frequency of operation, and control strategy.

The increase in the number of electric transport vehicles will also lead to an increase in the volume of end-of-life batteries. Once a battery reaches a condition in which it can no longer provide sufficient power and driving range for a vehicle, it can potentially be used in stationary energy storage systems. Such a “second-life” approach makes it possible to extend the overall service life of the battery and obtain additional value from it before recycling.

Therefore, an electric transport system under hot climate conditions can be considered according to the following chain:

Electric transport vehicle → charging system → EMS → electricity grid → V2G → secondary battery use.

This approach makes it possible to consider not only the role of an electric transport vehicle as a means of transportation but also its role as a flexible element of the energy system.

Prospects for Application under Central Asian Conditions

The high summer air temperatures in Central Asian countries require specific study of the operating conditions of electric transport vehicles. While the electrification of urban transport continues in the region, it is important to assess the real energy consumption and charging requirements of transport vehicles in accordance with local climatic conditions.

In particular, under the conditions of Uzbekistan, it is appropriate to include the following factors in the forecasting model:

- maximum and average summer air temperature;
- difference between daytime and nighttime temperatures;
- solar radiation;
- urban traffic congestion;
- passenger load;
- route length of electric buses;
- number of stops;
- air conditioning operating duration;
- battery SOC and SOH indicators;
- capacity and location of charging stations.

For electric buses, forecasting route-specific energy consumption is particularly important. For example, electric buses of the same model may consume different amounts of energy on different routes. This is caused by route length, traffic congestion, number of stops, passenger flow, and road profile.

Therefore, a forecasting system for Central Asia should be based not on universal manufacturer specifications, but on a local database of real-world operational data.

For this purpose, the following data can be systematically collected from electric buses:

$$\mathbf{D} = \{\mathbf{T}, \mathbf{V}, \mathbf{SOC}, \mathbf{SOH}, \mathbf{E}, \mathbf{L}, \mathbf{P}, \mathbf{H}, \mathbf{t}\}$$

Based on these data, a seasonal energy consumption profile can be developed for each route.

The forecasting results can be used for the following practical tasks:

- determining the daily charging requirements of electric buses;
- calculating the required capacity of charging stations;
- comparing energy consumption across transport routes;
- planning additional energy reserves for high-temperature days;
- optimizing the thermal management of batteries;
- developing daily operating schedules for electric buses;
- forecasting the maximum load on the electricity grid;
- integrating EMS and V2G systems in the future.

Conclusion and recommendations

The literature review conducted shows that the operational efficiency of electric transport vehicles under hot climate conditions is determined by the influence of several interrelated factors. Among them, ambient air temperature, battery thermal condition, SOC and SOH indicators, driving speed, road conditions, vehicle load level, and the energy consumption of the HVAC system play a major role.

Under hot climate conditions, assessing the energy consumption of an electric transport vehicle solely based on propulsion energy is insufficient. The energy demand of battery thermal management and passenger compartment cooling systems should also be included in the total energy consumption. Modern studies confirm that under extreme temperature conditions, HVAC and temperature-related battery losses can have a significant impact on the total energy consumption of an electric transport vehicle.

Based on the research findings, the following recommendations can be formulated:

First, ambient air temperature should be considered as a separate key variable when forecasting the energy consumption of electric transport vehicles.

Second, for electric buses, it is appropriate to use a multifactor model that takes into account the number of passengers, route length, number of stops, traffic congestion, and average speed when assessing energy consumption.

Third, under high-temperature conditions, the energy consumed by HVAC and battery thermal management should be calculated separately.

Fourth, the use of machine learning algorithms based on real-world operational data can improve the accuracy of energy consumption forecasting. In this regard, it is also important to consider the transparency and interpretability of the model.

Fifth, managing the charging process of electric transport vehicles through EMS makes it possible to distribute charging over time according to the load on the electricity grid.

Sixth, when implementing V2G technology, the vehicle's primary mobility requirements, minimum SOC level, and battery degradation should be considered jointly. V2G technology can provide flexibility to the grid; however, its effectiveness depends on the control strategy and battery service life.

Seventh, it is necessary to study the possibilities of secondary use of end-of-life electric vehicle batteries in stationary energy storage systems. This can extend the useful life of batteries removed from vehicles and create an additional resource for energy storage systems.

Overall, forecasting the efficiency of electric transport vehicles under hot climate conditions should be based on an integrated approach that considers the interrelationships among the vehicle, battery, climate, road, and energy systems. Such an approach can not only enable the advance determination of the actual driving range, energy consumption, and charging requirements of electric transport vehicles, but also contribute to improving the reliability and economic efficiency of urban electric transport systems.

Under Central Asian conditions, future research should focus on integrating telematics data obtained from real electric buses and electric vehicles with meteorological data. Based on temperature, humidity, solar radiation, traffic flow, speed, SOC, SOH, HVAC load, and route parameters, a local forecasting model can be developed. Such a model can subsequently be used as a practical tool for planning charging infrastructure, optimizing electric bus operating schedules, and developing energy management systems.

References

1. International Energy Agency (IEA). Global EV Outlook 2026. Paris: IEA, 2026.
2. International Energy Agency (IEA). Global Energy Review 2026: Technology – Electric Vehicles. Paris: IEA, 2026.
3. International Energy Agency (IEA). Global EV Outlook 2025. Paris: IEA, 2025.
4. International Energy Agency (IEA). Trends in Heavy-Duty Electric Vehicles. Global EV Outlook 2025. Paris: IEA, 2025.
5. Zhang X., Zhang Z., Liu Y., Xu Z., Qu X. A review of machine learning approaches for electric vehicle energy consumption modelling in urban transportation. *Renewable Energy*. 2024. Vol. 234. Article 121243.
6. Yuksel T., Michalek J.J. Effects of regional temperature on electric vehicle efficiency, range, and emissions in the United States. *Environmental Science & Technology*. 2015. Vol. 49, No. 6. P. 3974–3980. <https://doi.org/10.1021/es505621s>
7. Fiori C., Ahn K., Rakha H.A. Power-based electric vehicle energy consumption model: Model development and validation. *Applied Energy*. 2016. Vol. 168. P. 257–268. <https://doi.org/10.1016/j.apenergy.2016.01.097>
8. Kempton W., Tomić J. Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *Journal of Power Sources*. 2005. Vol. 144, No. 1. P. 268–279. <https://doi.org/10.1016/j.jpowsour.2004.12.025>
9. Bandhauer T.M., Garimella S., Fuller T.F. A critical review of thermal issues in lithium-ion batteries. *Journal of The Electrochemical Society*. 2011. Vol. 158, No. 3. P. R1–R25. <https://doi.org/10.1149/1.3515880>
10. Harper G., Sommerville R., Kendrick E., et al. Recycling lithium-ion batteries from electric vehicles. *Nature*. 2019. Vol. 575. P. 75–86. <https://doi.org/10.1038/s41586-019-1682-5>
11. Lajunen A. Energy consumption and cost-benefit analysis of hybrid and electric city buses. *Transportation Research Part C: Emerging Technologies*. 2014. Vol. 38. P. 1–15. <https://doi.org/10.1016/j.trc.2013.10.008>
12. Gallet M., Massier T., Hamacher T. Estimation of the energy demand of electric buses based on real-world data for large-scale public transport networks. *Applied Energy*. 2018. Vol. 230. P. 344–356. <https://doi.org/10.1016/j.apenergy.2018.08.086>
13. Liu K., Wang J., Yamamoto T., Morikawa T. Exploring the interactive effects of ambient temperature and vehicle auxiliary loads on electric vehicle energy consumption. *Applied Energy*. 2018. Vol. 227. P. 324–331. <https://doi.org/10.1016/j.apenergy.2017.08.074>
14. Vetter J., Novák P., Wagner M.R., et al. Ageing mechanisms in lithium-ion batteries. *Journal of Power Sources*. 2005. Vol. 147, No. 1–2. P. 269–281. <https://doi.org/10.1016/j.jpowsour.2005.01.006>
15. Uddin K., Dubarry M., Glick M.B. The viability of vehicle-to-grid operations from a battery technology and policy perspective. *Energy Policy*. 2018. Vol. 113. P. 342–347. <https://doi.org/10.1016/j.enpol.2017.11.015>.