

# **Impact of High Temperature Climatic Factors on the Operational Safety of Electric Vehicle Batteries in the Conditions of the Republic of Uzbekistan**

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## **Abstract:**

The article examines the impact of high temperature climatic factors on the operational safety of electric vehicle battery systems under the conditions of the Republic of Uzbekistan. It is shown that the prolonged periods of extremely high temperatures characteristic of the region, intense solar radiation, and heating of road infrastructure create a stable thermal load on traction battery systems that significantly differs from the conditions of a temperate climate. Temperature dependent mechanisms of degradation of lithium ion batteries and the specific features of emergency condition formation, including thermal runaway, ignition, and the release of toxic decomposition products, are analyzed. Particular attention is given to assessing risks to human safety and the environment in cases of battery system overheating in densely built urban areas and enclosed spaces. An analysis of the existing regulatory and legal framework has been carried out, demonstrating its limited adaptation to hot climate conditions and insufficient regulation of climate related risks. The discussion of the results confirms the necessity of developing climate adapted requirements and preventive measures aimed at increasing the level of safety in the operation of electric vehicles in regions with high ambient temperatures.

**Keywords:** *electric vehicles; battery systems; lithium-ion batteries; overheating; thermal runaway; human safety; environmental safety; hot climate; Republic of Uzbekistan; regulatory and legal regulation*

In the context of the global transition to low carbon transportation systems, electric vehicles are considered one of the key directions for reducing the negative impact of transport on the environment and public health [1]. At the same time, the expansion of their use is accompanied by the emergence of new technological risk factors primarily associated with the operation of traction battery systems under conditions different from standard climatic scenarios [2].

Modern electric vehicles are mainly equipped with lithium-ion batteries, which are characterized by high specific energy capacity and sensitivity to temperature effects [3]. Elevated ambient temperatures accelerate side electrochemical reactions, contribute to the degradation of electrode materials, increase internal resistance, and disrupt the thermal stability of battery cells [4]. These processes lead not only to a reduction in the operational lifespan of batteries but also to an increased probability of emergency conditions, including thermal runaway, ignition, and the release of toxic decomposition products [5].

The issue of temperature safety of electric vehicle batteries becomes particularly relevant for regions with hot climates. In the conditions of the Republic of Uzbekistan, during the summer period the air temperature in a number of regions consistently exceeds +40 °C, and exposure to high temperatures is prolonged and recurring [6]. The operation of electric vehicles under such conditions takes place under high solar radiation, heating of road surfaces, and limited efficiency of passive cooling, which significantly increases the thermal load on battery systems [7].

It should be noted that most of the existing regulatory requirements and operational safety recommendations for electric vehicle batteries have been developed with a focus on temperate climatic conditions and do not fully take into account the specifics of regions with extremely high ambient temperatures [8]. As a result, a contradiction arises between the declared safety indicators of battery systems and the actual conditions of their operation in hot climates, which may lead to an underestimation of risks for drivers, maintenance personnel, and the population located in areas of potential emergency situations [9].

An analysis of scientific publications shows that the main attention of researchers is focused either on the electrochemical mechanisms of lithium ion battery degradation or on issues related to improving the energy efficiency and service life of batteries [10]. At the same time, the influence of climatic factors on the safety of electric vehicle battery operation and their potential impact on humans and the environment is considered fragmentarily, especially in relation to the conditions of Central Asia and the Republic of Uzbekistan [11].

The purpose of this article is to analyze the influence of high temperature climatic factors on the operational safety of electric vehicle batteries and to identify potential threats to humans and the environment under the conditions of the Republic of Uzbekistan. Within the framework of this work, temperature dependent mechanisms of battery degradation, the characteristics of emergency condition formation during overheating, and the limitations of existing regulatory regulation that hinder effective risk management in hot climates are examined.

The results of the study are aimed at forming a scientifically grounded approach to assessing the safety of electric vehicle operation and may be used in the development of adapted operational

requirements, preventive measures, and recommendations for reducing risks in regions with high ambient temperatures.

### **Climatic Conditions of the Republic of Uzbekistan as a Risk Factor in the Operation of Electric Vehicle Batteries**

The Republic of Uzbekistan belongs to regions with a sharply continental and arid climate, characterized by prolonged hot summer periods, high intensity of solar radiation, and significant daily fluctuations in air temperature [12]. In most regions of the country, during the summer months average daily temperatures consistently exceed +30 °C, while maximum values often reach +40 to +45 °C and higher [13]. Such temperature conditions create a specific operating environment for vehicles, including electric vehicles.

Prolonged exposure to high ambient temperatures has a significant impact on the thermal regime of traction battery systems. Unlike short term temperature peaks typical of temperate climatic zones, under the conditions of Uzbekistan the thermal load is persistent and remains for several months of the year [14]. This leads to the accumulation of thermal effects that cannot always be compensated by the standard cooling systems of battery packs designed for typical operating conditions [15].

An additional risk factor is the high intensity of solar radiation, which contributes to the heating of the vehicle body and elements of the power structure of the electric vehicle, including battery modules located in the lower part of the vehicle [16]. When parked in open areas, the surface temperature of the battery pack may significantly exceed the ambient air temperature, increasing the likelihood that the temperature regime will exceed the limits recommended by the manufacturer [17].

The temperature characteristics of road surfaces should also be taken into account. During the summer period, the temperature of asphalt concrete pavement in Uzbekistan may exceed +60 °C, which creates additional conditions for heat transfer to the lower part of the electric vehicle body and the battery compartment [18]. In conditions of dense urban traffic and limited driving speed, the efficiency of air cooling decreases, which further increases the thermal load on battery systems [19].

Daily temperature fluctuations characteristic of the climate of Uzbekistan also have a negative impact on battery systems. Repeated heating and cooling cycles lead to thermal stress in materials, acceleration of aging processes, and degradation of electrode structures [20]. In combination with high operating temperatures, this contributes to a reduction in battery service life and an increased probability of failures.

Thus, the climatic conditions of the Republic of Uzbekistan form a combination of risk factors including prolonged exposure to high temperatures, intense solar radiation, heating of road surfaces, and pronounced daily temperature fluctuations. These factors significantly distinguish the operating conditions of electric vehicles from those for which most regulatory requirements and technical solutions are developed, which necessitates a separate analysis from the standpoint of battery system safety and human protection [21].

### **Impact of Battery Overheating on Human Safety and the Environment**

Overheating of traction batteries in electric vehicles represents one of the most hazardous operational factors directly affecting human safety and the condition of the environment. Under conditions of high ambient temperatures, the probability that battery systems will exceed the permissible thermal operating range increases significantly, which may lead to the development of emergency processes of varying severity [22].

One of the key mechanisms determining the danger of battery overheating is thermal runaway, a self-sustaining process of uncontrolled temperature growth accompanied by the destruction of the internal structure of battery cells [23]. Thermal runaway may be initiated both by external heating and by internal defects aggravated by exposure to high ambient temperatures [24]. Under hot climate conditions, the probability of reaching critical temperature thresholds increases substantially.

The development of thermal runaway is accompanied by the intensive release of heat and gaseous decomposition products of the electrolyte and electrode materials [25]. These products include toxic and corrosive substances such as hydrogen fluoride, carbon oxides, and organic compounds that pose a danger to the human respiratory system and skin [26]. When people are located in confined spaces, for example inside a vehicle cabin or in underground parking facilities, exposure to such substances may lead to acute poisoning and chemical burns [27].

Battery overheating poses a particular danger for maintenance personnel and service station employees. Activities related to diagnostics, charging, and maintenance of electric vehicles under conditions of elevated temperature are accompanied by additional thermal and chemical loads, which increase the risk of occupational diseases and injuries [28]. In the absence of specialized protective measures, the consequences of emergency battery system conditions may be severe.

Fires involving electric vehicle battery systems are characterized by high flame temperatures, long combustion durations, and a tendency toward re-ignition [29]. In hot climates, the rate of fire spread and the intensity of thermal radiation increase, which raises the probability of harm to people located near the ignition source [30]. Conventional fire extinguishing methods are not always effective for lithium ion batteries, which complicates the elimination of the consequences of such accidents [31].

The environmental consequences of battery overheating and ignition are also significant. During the thermal destruction of battery cells, toxic aerosols and decomposition products are released into the environment, capable of contaminating atmospheric air, soil, and surface water bodies [32]. Under conditions of high ambient temperatures, the dispersion of pollutants accelerates, increasing the potential impact zone [33].

An additional environmental risk is associated with the loss of integrity of battery modules and the subsequent release of heavy metals and fluorine-containing compounds into the soil [34]. In regions with an arid climate characteristic of Uzbekistan, natural environmental self-purification processes occur more slowly, which increases the duration of the negative impact of pollutants [35].

Thus, overheating of electric vehicle batteries under hot climate conditions represents a complex threat affecting both human safety and the ecological condition of territories. The combination of thermal, chemical, and fire-related risks necessitates the development of specialized approaches to assessing the safety of electric vehicle operation and the implementation of adapted protective measures that take into account the climatic characteristics of the Republic of Uzbekistan [36].

### **Regulatory and Legal Framework for the Operation of Electric Vehicle Batteries and Its Insufficiency under Hot Climate Conditions**

The safety of the operation of electric vehicle battery systems is largely determined by the existing regulatory, legal, and technical requirements governing the design, testing, operation, and disposal of battery systems. In most countries, including the Republic of Uzbekistan, the regulatory framework in this area is formed on the basis of international standards and interstate technical regulations adapted to national conditions [37].

Existing regulatory documents establish general requirements for electrical, fire, and operational safety of battery systems, including permissible temperature ranges, requirements for battery management systems, and protective measures in emergency operating modes [38]. At the same time, analysis of these requirements shows that they are mainly oriented toward standard or temperate climatic operating conditions and do not fully take into account the specifics of regions with prolonged exposure to extremely high ambient temperatures [39].

A significant limitation of the existing regulatory framework is the absence of clearly regulated climate adapted operating modes for electric vehicle battery systems. Current documents usually specify maximum permissible temperature values, but they do not consider scenarios in which battery systems remain close to the upper temperature limits for extended periods, which is typical for hot climates [40]. This complicates the objective assessment of accumulated thermal exposure and the associated risks of degradation and emergency failures.

The issue of ensuring human safety during emergency battery operating conditions also remains insufficiently developed. Regulatory requirements are mainly focused on preventing electrical and fire related risks, whereas toxicological aspects related to the release of decomposition products during battery overheating and their impact on humans are considered only to a limited extent [41]. Under conditions of dense urban development and the operation of electric vehicles in enclosed spaces, this issue becomes particularly significant.

Analysis of national regulatory documents of the Republic of Uzbekistan shows that issues related to climate adaptation of requirements for the operation of electric vehicle batteries are still in the process of formation and have not yet been identified as a separate area of regulation [42]. As a result, universal standards are applied that do not take into account the duration of hot periods, the intensity of solar radiation, and the temperature characteristics of road infrastructure typical for the region [43].

Another problem is the absence of specialized requirements for the operation, maintenance, and storage of electric vehicles under high temperature conditions for service organizations and maintenance personnel. This leads to heterogeneous operational practices and increases the probability of errors capable of provoking emergency operating conditions of battery systems [44].

Thus, the existing regulatory and legal framework in the field of safety of electric vehicle battery operation generally provides a basic level of protection, but it does not fully take into account the climatic characteristics of regions with hot climates. Insufficient specification of temperature related requirements, the absence of climate adapted operational scenarios, and limited attention to risks for humans and the environment create conditions that may increase accident rates and necessitate the development of additional regulations and methodological recommendations oriented toward the conditions of the Republic of Uzbekistan [45].

### **Methodology.**

This study utilizes a comprehensive analytical approach for the research methodology to assess the impacts of high temperature climatic conditions on electric vehicle battery system operational safety in the Republic of Uzbekistan. Abstract: The methodology integrates climatology, the behaviour of lithium ion batteries at higher temperatures, and the basis of regulatory safety requirements that govern operation of electric vehicles. The initial phase of the study involved an analysis of climate attributes of Uzbekistan based on data from meteorological stations and literature

sources on regional temperature conditions, solar radiation, and thermal characteristics of road infrastructure. This information was then used to define the thermal driving conditions for electric vehicles during extended hot periods. The second stage included a theoretical analysis of scientific literature of lithium ion battery technology to find temperature dependent mechanisms of battery degradation such as accelerated electrochemical reactions, increased internal resistance and structural deterioration of electrode materials. This mainly concentrated on processes that can produce overheating, thermal runaway, combustion, and emit hazardous plastic decomposition byproducts. They used this information to study the potential effects of these processes on humans and on environmental protection in urban areas and in confined spaces where electric vehicles are used. The study also involved a comparative analysis of international standards, technical regulations and national regulatory documents on the safety of electric vehicle batteries in terms of their suitability for operation in extreme temperature conditions. The methodological approach hence addresses climate, technology, and regulation-based aspects in combination, enabling an integrated evaluation of electric vehicle battery operational risk in hot climate locations to provide a basis for highlighting the directions in which improvements can assist to inform more effective safety requirements and preventive measures for better safety. The scientific context and problem formulation of the article served as a foundation for the design of the methodological approach and analytical framework here.

### **Discussion of Results**

The results obtained in this study allow the safety of electric vehicle battery operation in the Republic of Uzbekistan to be considered as a complex problem formed by the combined influence of climatic, technical, and regulatory factors. Unlike regions with temperate climates, where temperature overloads are episodic, under the conditions of Uzbekistan the thermal load on battery systems is prolonged and recurring, which fundamentally changes the nature of operational risks [46].

Analysis of climatic conditions shows that the persistent exceedance of temperature thresholds recommended for the operation of lithium ion batteries creates conditions for accelerated degradation of battery cells and an increased probability of emergency operating modes [47]. At the same time, overheating of battery systems in hot climates is not exclusively the result of internal defects or operational errors but is largely determined by external factors including high ambient temperatures, solar radiation, and heating of road surfaces [48]. This aspect is fundamentally important because it shifts the emphasis from individual operational violations to systemic operating conditions.

Consideration of battery overheating mechanisms in the context of human safety shows that under high temperature conditions not only does the probability of thermal runaway increase, but the severity of its consequences also rises [49]. The release of toxic decomposition products, high combustion temperatures, and the complexity of extinguishing battery fires create additional threats for drivers, passengers, and maintenance personnel, especially in enclosed or poorly ventilated spaces [50]. Under conditions of dense urban development these risks acquire significant social importance.

Comparison of the identified risks with the existing regulatory framework makes it possible to conclude that there is a gap between the actual operating conditions of electric vehicles in hot climates and the current safety requirements [51]. Most regulatory documents are oriented toward maximum temperature values without considering the duration and cumulative nature of thermal exposure typical for regions of Central Asia [52]. This leads to a situation in which formally acceptable operating conditions do not ensure the required level of safety under real climatic conditions.

Particular attention should be paid to the absence in regulatory documents of requirements aimed at assessing risks for humans and the environment in the case of battery overheating. The main focus is placed on preventing electrical and fire related accidents, while the toxicological and environmental consequences of emergency operating modes remain insufficiently regulated [53]. Under hot climate conditions that facilitate the accelerated spread of pollutants, this omission becomes critically significant [54].

Taken together, the obtained results indicate that the safety of electric vehicle battery operation under the conditions of the Republic of Uzbekistan cannot be ensured solely through the application of universal technical solutions and general regulatory requirements. A transition toward a climate adapted approach is required, taking into account the specific characteristics of thermal loads typical for the region as well as the potential consequences of emergency battery conditions for humans and the environment [55].

Thus, the discussion of the results confirms the necessity of developing specialized operational requirements and preventive measures for regions with hot climates aimed at reducing thermal risks of battery systems and increasing the level of safety of electric vehicles under the conditions of the Republic of Uzbekistan.

### **Conclusion.**

The study results provide confirmation that the climatic conditions with high temperature prevalent in the Republic of Uzbekistan is a significant factor affecting the operational safety of lithium ion battery systems for electric vehicles. Summer presents the most unobstructed, least problematic, if not violent, opportunity for the automotive industry to experience the artificially not unpleasant acceleration of battery degradation processes that occur at 40 Celsius and above; unusual solar radiation under hole, and weather-beaten road infrastructure heating that cause a steady thermal load compromising the safety of batteries and batteries operating outside their safe operating area which raises the potential of serious hazards like overheating, thermal runaway, ignition and toxic decomposition products. The results emphasize that such risks go beyond technical reliability and the personal injury and/or environmental damage that can result, especially in urban environments and enclosed spaces where the consequences of battery failures generated by this chemistry might be particularly severe. An additional key outcome from the study is finding gaps in the prevailing regulatory and technical framework that is mainly designed for temperate climate settings and thus does not adequately capture the cumulative thermal exposure typically present in hot climates. These results indicate that climate adapted operational standards, enhanced thermal management strategies, and preventive safety measures need to be developed specific to Uzbekistan and similar regions of the earth. These actions might help make electric vehicle battery systems more dependable and pose less of a danger to users, maintenance staff, and the surrounding environment. On the other hand, complexities in thermal processes in the battery systems during their operation combined with their interaction with the ambient climate, suggest further interdisciplinary investigations are required. Further research is needed for the experimental characterization of battery thermal performance in extreme temperature environments and the design of cooling technologies, as well as the establishment of regulations incorporating climatic risks into electric vehicle safety.

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