Using electric vehicles as emergency power sources for extreme weather

Zhengguang Liu,[1,2] Ying Du,[1,3] Dongxiao Zhang,[1] and Yuntian Chen[1,*]
[1]Zhejiang Key Laboratory of Industrial Intelligence and Digital Twin, Eastern Institute of Technology, Ningbo 315104, China
[2]Department of Engineering, The University of Manchester, Manchester M1 7HF, UK
[3]Department of Building Environment and Energy Engineering, The Hong Kong Polytechnic University, Hong Kong 999077, China
*Correspondence: ychen@eitech.edu.cn
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Dear Editor,

The increasing frequency and intensity of extreme weather events pose significant risks and challenges to urban power systems. In September 2024 alone, typhoons caused losses exceeding 10 billion yuan in Wenchang, Hainan, with some areas experiencing power outages lasting over 40 hours. The same tragedy also happened in the power outage after the earthquake in Myanmar and the power outage caused by heavy snow in Texas. Without proactive measures, such disasters are likely to recur, exacerbated by the increasing frequency of extreme weather events. Simultaneously, the rapid growth of electric vehicle (EV) sales in China, with over 1.3 million units sold in October 2024, has brought new opportunities.[1] Given their high energy density batteries and camping mode functionality, electric vehicles can provide stable external power and serve effectively as mobile emergency power sources and temporary shelters during extreme weather events, thereby mitigating urban power shortages caused by the disasters.

China decided to realize a full transition to a new energy system by 2050, with wind and solar power contributing 54% of the total power generation.[2] However, the inherent volatility of renewable energy sources and their vulnerability to extreme weather impacts will likely render future urban power systems not only inadequately equipped to handle extreme disasters but also deficient in emergency response capabilities. Many studies have discussed the use of Vehicle-to-Grid (V2G) technology post-disaster, but in such scenarios, the power grid itself may already be collapsed. Therefore, it is necessary to consider the direct power supply from electric vehicles (EVs). This requires real-time monitoring and prediction of the distribution of EVs at the urban or national level, especially the spatiotemporal distribution of remaining battery capacity. This was previously unfeasible, but with the advancement of big data, artificial intelligence, and smart city technologies, as well as the development of human mobility tracking, this task has gradually become technically feasible. In this context, the burgeoning fleet of electric vehicles presents both a challenge and an opportunity. If not actively integrated into emergency response plans, electric vehicles could place additional strain on the already fragile urban power grid due to large load fluctuations and inconsistent standards, further increasing the risk of power outages. On the other hand, if properly managed, electric vehicles have the potential to serve as mobile emergency power sources, providing critical support during extreme weather events and enhancing the resilience of urban power systems.[3] Thus, there is an urgent need to establish a unified management system with time-space map for urban electric vehicles in the context of extreme disasters. This system would leverage spatiotemporal big data for real-time analysis and enable in-situ energy supply during disaster scenarios, allowing every vehicle within the city to function as a mobile emergency power source, meeting the energy demands of urban residents' daily lives and critical services. Additionally, given the current inconsistency in charging infrastructure standards and management, it is essential to establish a unified framework for electric vehicle energy distribution to facilitate distributed, in-situ energy supply.

By harnessing the significant potential of electric vehicles, we can transform them into effective emergency response tools, ensuring that EVs on the road provide an emergency energy guarantee for every urban resident.[4] Electric vehicles (EVs) can enhance the resilience of power grids against disasters by functioning as mobile distributed energy resources. For medium- and long-term disaster response like 3-7 days, it is also critical to implement efficient dispatch systems for electric vehicles based on load response. Essentially, EVs serve as mobile distributed emergency energy storage nodes, enabling a more flexible and decentralized energy system. Priority should be given to critical infrastructure such as hospitals, schools, and government facilities to ensure they remain operational during disasters, especially considering the unpredicted human activities. By developing an integrated regional or even national electric vehicle emergency response platform, new solutions for disaster management in urban areas could be realized, enhancing the resilience of cities in the face of future extreme weather events.

FREQUENT EXTREME WEATHER EVENTS HAVE INCREASED THE RISK OF POWER OUTAGES IN CITIES

In recent years, numerous major power safety incidents triggered by extreme weather events, both worldwide, have significantly impacted economic and social development, as well as global energy transition efforts. In February 2021, a winter cold wave in the United States led to the shutdown of numerous wind power and other generation units in Texas, leading to a sixfold increase in electricity prices. In August 2022, a rare combination of high temperatures and drought in Sichuan, China, resulted in a halving of natural water supply and a surge in electricity demand, leading to a severe power shortage that persisted for several weeks. The increasing frequency of extreme weather events worldwide has posed severe challenges to the rapidly growing renewable energy systems. In September 2024, Typhoon "Makar" caused direct economic losses exceeding 40 billion yuan to power infrastructure across four cities and counties—Haikou, Wenchang, Chengmai, and Lingao—accounting for 5.3% of Hainan's GDP from the previous year in China. The wind turbines were damaged and the minimum cost of repairing each wind turbine exceeds 3 million yuan, representing a significant financial loss. These events underscore the vulnerability of energy systems, particularly renewable energy sources, to extreme weather, and highlight the urgent need for resilient and adaptive infrastructure to safeguard energy security in the face of such challenges.

According to the International Energy Agency (IEA),[3] extreme weather events could result in direct economic losses of more than 100 billion yuan for China's renewable energy system over the next five years. This number will be even larger when compared with the whole world. Prolonged rainfall and typhoons in the south, coupled with high temperatures or cold waves in the north, pose a significant risk of long-term power shortages in China's key economic and political centers. More than 40 million residents in the China's capital could be affected by such power shortages in the future. Additionally, summer heatwaves exacerbate the imbalance between electricity demand and supply. In 2022, power restrictions and shortages in Sichuan raised concerns about potential nationwide power crises, particularly in regions such as Xinjiang, Tibet, and Inner Mongolia —key areas for new energy development under China's dual carbon goals. In addition to China, other developed economies have not been spared. In June 2023, a summer storm hit the southern United States, causing power outages for more than 300,000 residents. In February 2024, lightning strikes and storms hit Melbourne, Australia, causing damage to a large number of power supply facilities. With extreme weather becoming more severe, the risk of power shortages is increasing also.

Beyond the direct infrastructure losses caused by extreme weather, such events severely disrupt the supply chains of both upstream and downstream

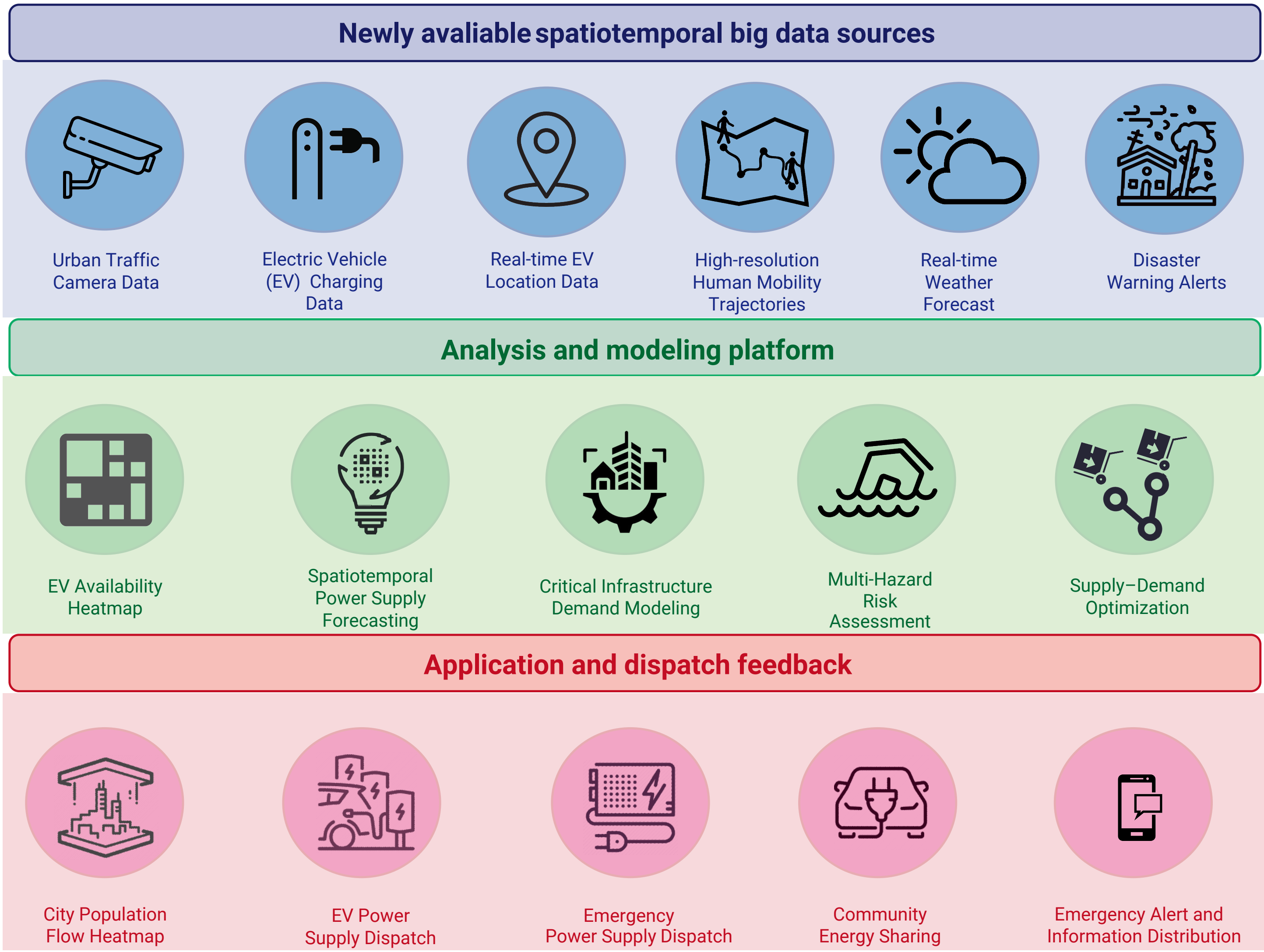

Figure 1. Framework for utilizing electric vehicles as emergency energy sources based on spatiotemporal big data

power users. The shutdown of manufacturing equipment, delays in infrastructure repairs, and interruptions to power supply not only pose significant risks to personnel and property safety but also result in substantial losses in reputation. In stark contrast, hundreds of thousands of electric vehicles (EVs) within urban areas remain largely underutilized, with many serving no role in mitigating power shortages. Considering that many EVs are now equipped with camping modes, which maximize energy efficiency by recycling battery power and can also provide an external power supply, the underuse of this valuable asset is concerning. Furthermore, this capacity will increase in line with the rapid growth of EVs. Therefore, it is imperative to establish effective management of electric vehicles and develop a new emergency response system to address urban electricity shortages during extreme weather events.

CURRENT ELECTRIC VEHICLE STANDARDS ARE INCONSISTENT AND DIFFICULT TO MANAGE EFFECTIVELY

Although the electric vehicle (EV) industry has experienced rapid growth in recent years, achieving record-high sales, the management of the industry remains relatively fragmented. Standards vary across different companies, making equipment difficult to standardize and resulting in limited interoperability. According to data from the China Association of Automobile Manufacturers, from January to October 2024, the production and sales of new energy vehicles (NEVs) exceeded 9.75 million units per month on average, with NEV sales accounting for 39.6% of total new vehicle sales in China. However, due to incompatibilities between equipment used by different EVs, these vehicles are unable to serve as reliable energy storage solutions during extreme disaster conditions, leaving them largely ineffective in addressing the current energy storage shortages in the power market. In such extreme scenarios, EVs often remain in place without response, if they cannot obtain effective charging style or same standards of charge after moving, unable to contribute meaningfully. Additionally, the lack of unified standards for EVs to connect to the power grid further limits their potential for widespread utilization. This issue significantly impedes the broader adoption and integration of EVs. Insufficient charging infrastructure, uneven regional distribution, and inconsistent technical standards significantly hinder the development of new energy vehicles. Moreover, the uncontrolled proliferation of charging stations could alter the load structure and characteristics of the distribution network under extreme weather conditions, complicating grid management and reducing the ability of urban power grids to respond effectively to such crise.[5] A systematic analysis and comprehensive planning for EV integration into the grid are therefore urgently needed.

WHAT SHOULD WE DO IN THE FUTURE

1.National-Scale Emergency Energy Dispatch Modeling and High-Resolution EV Time-space Map Applications: Currently, there is a lack of national-scale spatio-temporal modeling for emergency energy dispatch, particularly in terms of high-resolution modeling, trajectory prediction, and decision support systems for EVs. Existing studies mostly focus on local regions and employ coarse-grained methods to describe the role of EVs, which are insufficient for rapid, cross-regional emergency energy dispatch needs.

To address this gap, we propose developing a national-scale emergency energy dispatch model, integrating high-resolution multimodal data, including human mobility trajectories, electric vehicle trajectories, EV operational status estimation, and energy consumption patterns of different EV brands, to achieve precise modeling and accurate trajectory prediction. Additionally, by continuously monitoring and forecasting the real-time status of EVs on the road, including their estimated remaining battery capacities, this model generates a real-time spatio-temporal distribution map of actual remaining energy in urban electric vehicles. Such comprehensive, dynamic mapping is essential for immediately understanding the distribution of available EV energy resources in a city following any disaster occurrence, thereby effectively supporting rapid, cross-regional emergency energy dispatch and disaster response. Furthermore, we should develop advanced decision support systems to simulate and optimize the deployment of power and vehicle resources across various disaster-stricken areas. This model innovatively combines spatial location, temporal evolution, and real-time energy status information, enabling dynamic assessment and optimization of EV capabilities for power supply, thereby providing the scientific basis for rapid, targeted emergency responses in the event of extreme weather disasters.

It is worth noting that these ambitious objectives were previously unattainable due to technological and data limitations. However, with the widespread implementation of 5G networks, advancements in smart city development, enhanced urban big-data infrastructures, and ongoing evolution in IoT and artificial intelligence technologies, these goals have now become realistically achievable.

2.Direct Power Supply Utilization of EVs in Post-Disaster Off-Grid Scenarios: In the aftermath of large-scale natural disasters, conventional power grids often fail to provide adequate support. Under such extreme conditions, EVs can serve as independent nodes of direct current (DC) power supply. However, comprehensive studies on this application scenario are still lacking. Future study should treats EVs as mobile DC power source nodes, conducting in-depth research into the specific challenges of direct DC supply, including the integration with on-site photovoltaic generation, energy storage, and DC-flexible distribution systems. Our work addresses the deficiencies in existing literature regarding EVs' emergency power applications under off-grid conditions, proposing an integrated "EV-PV-storage" temporary power network architecture to provide reliable power support in post-disaster off-grid areas. This not only expands the concept of EV emergency applications but also holds practical significance for enhancing self-rescue capabilities during disasters.

3.Coupled Analysis of Post-Disaster Human Mobility and Power Restoration: We recognize the relative lack of research on post-disaster human mobility and behavioral responses, which are crucial factors in emergency power strategy formulation. During extreme disasters and weather conditions, evacuation, resettlement, and return patterns of populations directly impact electricity demand and priority. However, few studies systematically integrate power system restoration strategies with dynamic analyses of human mobility involving EVs. We propose exploring this intersection by establishing spatiotemporal distribution prediction models of post-disaster human mobility and coupling them with power restoration strategies. Additionally, it should be considered whether the irrational response willingness of EV users needs to be incorporated into the analysis, as users' decisions to participate in emergency power provisioning could be influenced by psychological factors, perceived risks, or inconvenience. Through interdisciplinary integration and consideration of human behavioral factors, we aim to evaluate the impact of various emergency power supply strategies on the well-being of affected populations, ensuring that power scheduling decisions better align with real-world human behaviors and needs. Ultimately, this letter seeks to enrich the formulation of emergency power strategies from a human-centric perspective, holding positive implications for disaster response.

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DECLARATION OF INTERESTS

The authors declare no competing interests.