Electric Vehicles in Emergencies and Evacuations: A Review of Resilience and Future Research Directions

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Abstract

Disasters often require large-scale evacuations, and damage key infrastructure (e.g., power, transportation). With growing electric vehicle (EV) adoption and electrification of transportation, governments and utilities may face significant power challenges during disasters, especially during the evacuation stage. Low state-of-charge, sporadic charging infrastructure, or power outages could significantly hamper safe and effective evacuations. Yet, EVs also offer possible resilience benefits to emergency response by more easily charging electronics or sending power back to the grid through vehicle-to-grid (V2G) technology. This paper focuses on the opportunities, benefits, and drawbacks of EVs in disasters and evacuations through a systematic review of current literature, reports, and sources. Overall, this review discovered EVs show promise as modes of transportation and mobile energy supply units. However, crucial challenges such as charging infrastructure locations, upfront cost of resilience technologies, and user behavior necessitate more dedicated research to overcome shortcomings and guide more realistic implementation of benefits.

Keywords: Electric Vehicles, Resilience, Disasters, Emergencies, Power Outage, Evacuation

1. INTRODUCTION

The adoption rate of electric vehicles (EVs) has been steadily growing over the past decade as battery prices fall, production ramps up, and incentives increase. EVs comprised 14 percent of new car sales globally in 2022 (IEA, 2023). The steady adoption of EVs carries both challenges and novel opportunities, as EVs can act as both modes of transportation as well as energy storage and supply systems (Yang et al., 2020b). With continued acceptance and interest from consumers (Adderly et al., 2018), EV adoption is now faced with the challenge of meeting user needs apart from normal conditions, specifically during disaster scenarios. This includes access to charging infrastructure resilient to disasters such as large-scale power outages and wildfires (Rahimi & Davoudi, 2018). Risk-reduction measures, such as public safety power shutoff (PSPS) events in California, also pose an issue to EV adoption and resilience, requiring more research and resilient policies (Wong et al., 2022).

Focusing on possible benefits, EVs can act as energy storage devices that can potentially return power back to the grid for usage by other devices (Yang et al., 2020b). A community suffering from a loss of power can use EVs as mobile power sources (MPSs) by supplying power back to the grid, improving community resilience and long-term recovery (Lei et al., 2019). These challenges and benefits have yet to fully materialize as only a few anecdotal examples of EV use cases in disasters exist. The 2011 Japanese Tohoku earthquake and its ensuing tsunami heavily damaged oil refineries and destroyed road, which hampered resource deliveries. During the aftermath of the disaster, EVs proved instrumental in transporting food, medical professionals, and vital medicine since the vehicles could refuel via a common electrical outlet. Though limited, the vehicles' range was ideal for smaller Japanese cities since they could be driven on a single charge during the day and returned to tow centers to charge at night. (Belson, 2011). Similarly, when power outages and generator failures impacted communities during California wildfires in 2015, Pacific Gas and Electric (PG&E) utilized a plug-in hybrid truck to provide power to several hundred residents for two days until replacement generators were procured. Subsequently, the company announced plans to invest one-third of its annual fleet budget, amounting to USD 100 million, on plug-in vehicles (Morris, 2015).

Despite these examples, most disaster plans or protocols do not require an analysis of EV needs during extreme events (Donaldson et al., 2020). Moreover, EV user behavior and the resilience of EVs during natural disasters have been relatively under-researched. Our objective in this paper is to address these gaps by providing an early understanding of the advantages of EV use in disasters as well as impediments to the safe and effective operation of these vehicles surrounding evacuations. We seek to answer the following questions:

1) What are critical EV barriers and challenges in disasters and evacuations?
2) What are the benefits and optimal strategies for EVs in disasters and evacuations?
3) How can future research address gaps in knowledge while incorporating EV resilience in disasters?

To answer these questions, we conducted a systematic review of EV literature that focuses on resilience and/or evacuations. For bounding the review within a clear scope, this paper focuses on barriers and challenges faced by EVs during disasters, benefits and potential advantages of EVs in emergency scenarios, and future research directions that enhance our understanding and preparedness with regard to EVs. Additionally, while we explore user behaviour within the context of choices made in an emergency, we do not address behaviour as it pertains to public resistance to EV adoption and other reservations towards electrified mobility.

This paper is organized as follows. First, we elaborate on the various challenges faced by EVs currently. Second, we provide a detailed analysis of research into the benefits of using EVs in disasters through different strategies. A section is then dedicated to a review of policies surrounding EV use during disasters. We then provide a discussion on the key takeaways from our review and end with conclusions.

2. METHODOLOGY

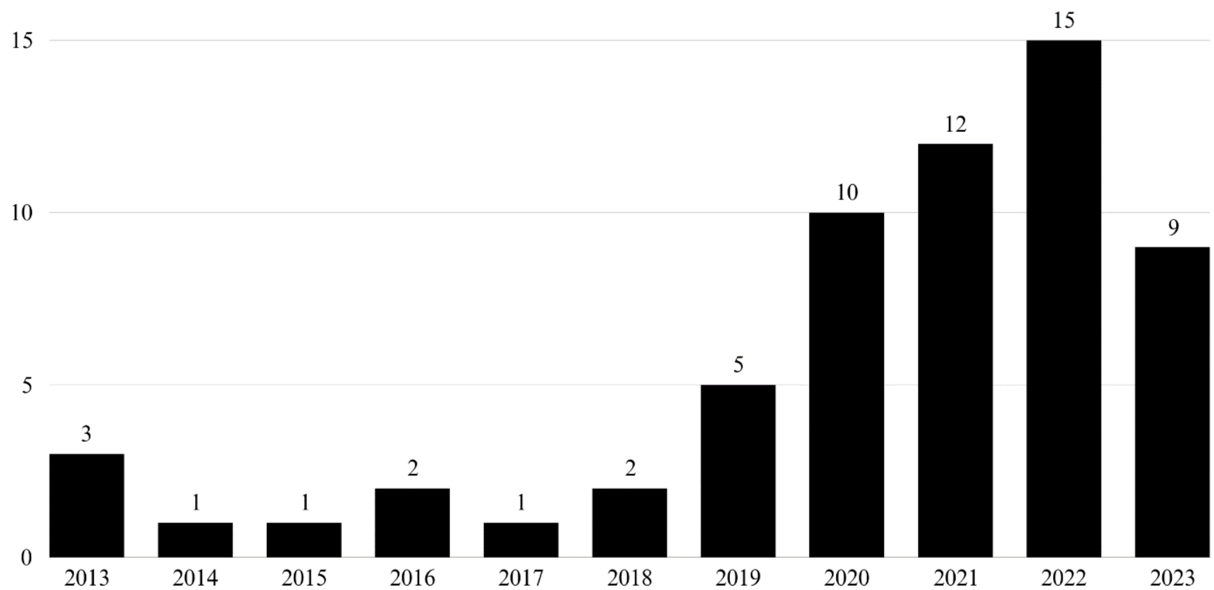
We conducted a systematic review on EVs, resilience, and evacuations using a keyword search for papers published between 1980 and 2023 on the peer-reviewed databases of Scopus, Taylor & Francis, and Transport Research International Documentation (TRID). The keyword string utilized to locate papers was as follows: evacuation* OR route planning OR resilien* OR prepar* AND electric vehicle* OR alternate fuel vehicle* AND disaster* OR emergenc* OR wildfire* OR hurricane* OR tsunami* OR hazard* OR extreme weather event*. Focusing on titles and abstracts, the query provided 333 results across all databases which were screened for relevancy over multiple stages, resulting in 63 articles. Three articles were written in languages other than English and were omitted from the review, leaving 60 sources (mostly journal articles). A final search for sources using Google Scholar (to determine if any additional literature was missed) added one article to the list, bringing the total number of peer-reviewed sources to 61.

Our systematic review is limited by our choice in the publication databases and the restriction of English-only papers. We also excluded a significant amount of literature related to grid resilience, as articles did not have immediate transportation implications. Since EV resilience is an emerging area of research and practice, we may not have captured all current literature, especially reports and policy briefs from gray literature. The search string may also have failed to capture literature on the topic, especially those that discuss EV resilience or evacuations in the body of the article (as opposed to the title or abstract) or conduct work on topics that are indirectly related to the research questions. We note this as a key limitation to the research that may have reduced the total number of relevant articles for review.

2.1) Overview of Literature

The development of commercial, mass-market EVs has been rapid and fast-paced, with significant growth in the past decade. This has been spurred by a number of factors including (but not limited to) technological developments (especially for batteries), sustainability concerns for internal combustion engines (ICE), and a shifting policy landscape that has begun promoting electrified transportation. In our review, this advancement in EVs is reflected in the research landscape within the disaster and resilience contexts. While studies on this topic are generally scarce compared to the evacuation/disaster field as a whole, Figure 1 shows the distribution of the 61 articles on EVs in emergencies and evacuations. Most research has been conducted in the past five years with a general trend upward. This matches the rise of EV adoption along with growing concerns of climate-related hazards that are increasing in size, frequency, and scope. Though the initial year of 1980 for the review was used to account for the early mass production of EVs, literature on evacuation and resilience considerations of EVs was not produced until 2013 (see Figure 1).

Figure 1. *Distribution of Peer-Reviewed Sources Based on Publication Year (n=61 sources)*



The core of the review goes beyond this time-based distribution by structuring the research topically. We grouped the articles in the review into two large sections that generally follow the first two research questions. Papers related to policy are also included in the review. Future research directions (i.e., the third research question) are provided in the discussion section based on the review. Figure 2 presents this framing, along with the discovered topics, while Table 1 provides the sources within the framework. A secondary grouping was conducted based on the disaster phase, which is explored in the discussion section.

Figure 2. *Key Research Topics*

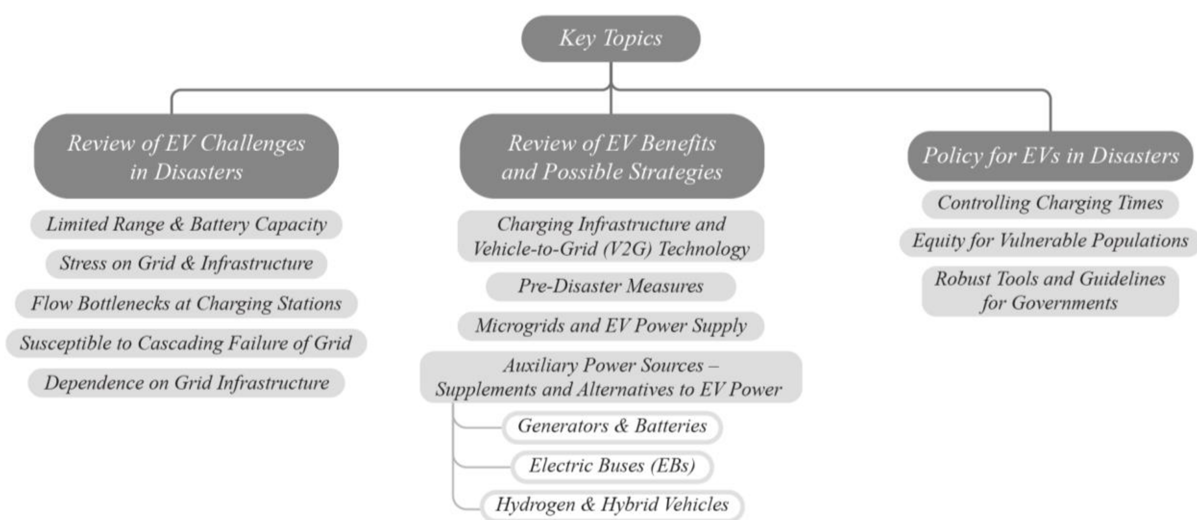


Table 1. *Peer-Reviewed Sources Grouped by Framework*

Section 3: Review of EV Challenges in Disasters		
Summary	**Sources***	
3) Review of EV Challenges in Disasters: Overview of the challenges and limitations faced by EVs in emergencies such as limited capacity, infrastructure, and charging speed *11 sources*	• Adderly et al., 2018 • Macdonald et al., 2021 • Donaldson et al., 2022 • Razeghi et al., 2021 • Rahimi & Davoudi, 2018 • Purba et al., 2022	• Li et al., 2022b • Feng et al., 2020 • Hussain & Musilek, 2022 • Maharajan et al., 2015 • Momen et al., 2020
Section 4: Review of EV Benefits and Possible Strategies		
Summary	**Sources***	
4.1) Charging Infrastructure and Vehicle-to-Grid (V2G) Technology: Exploring the role of fast charging stations and V2G technology in enhancing EV resilience and integration into the energy grid *15 sources*	• Rahimi & Davoudi, 2018 • Purba et al., 2023 • Zhang et al., 2022b • Hussain et al., 2020 • Liu et al., 2023b • Hussain & Kim, 2021 • Hussain & Musilek, 2022 • Razeghi et al., 2021	• Yamane et al., 2019 • Yang et al., 2019a • Abdubannaev et al., 2021 • Momen et al., 2021 • Alizadeh and Jafari-Nokandi, 2023 • Yamagata et al., 2013 • Ali et al., 2020
4.2) Pre-Disaster Measures: Measures to be taken before disasters to enable consistent and reliable EV operations *11 sources*	• Gazijahani et al., 2022 • Candan et al., 2023 • Tian & Talebizadehsardari, 2021 • Lei et al., 2019 • Yang et al., 2020a • Erenoğlu et al., 2023	• Li et al., 2022b • Feng et al., 2020 • Donaldson et al., 2022 • Wu et al., 2022 • Liu et al., 2023b
4.3) Microgrids & EV Power Supply: Utilizing EVs to provide power to microgrids and other self-sustaining grids *16 sources*	• Gouveia et al., 2013 • Gholami et al., 2016 • Ali et al., 2020 • Alizadeh & Jafari-Nokandi, 2023 • Marami Dizaji et al., 2019 • Razeghi et al., 2021 • Hasan et al., 2021 • Hussain & Musilek, 2022	• Ebadat-Parast et al., 2022 • Momen et al., 2021 • Simental et al., 2022 • Ding et al., 2020 • Erenoglu et al., 2022 • Momen et al., 2020 • Yadav et al., 2021 • Yamamura & Miwa, 2014
4.4) Auxiliary Power Sources – Supplements and Alternatives to EV Power: Providing additional electricity supply via both stationary sources (e.g., generators, batteries) and mobile	*Generators and Batteries* • Ding et al., 2020 • Gao et al., 2017 • Momen et al., 2021 • Moore et al., 2020	• Simental et al., 2022 • Saitoh et al., 2013 • Yadav et al., 2023 • Liu et al., 2023a

sources such as electric buses, hydrogen fuel cell vehicles (HFCVs), and plug-in hybrid vehicles (PHEV) *20 sources*	• Guo et al., 2021	• Maharjan et al., 2015
	Electric Buses	
	• Zhang & Zhang, 2022 • Li et al., 2022a • Li et al., 2021a • Tessler & Traut, 2022	• Gao et al., 2017 • Sayed & Gabbar, 2016
	HFCVs and PHEVs	
	• Dong et al., 2023 • Cao et al., 2023	• Abessi et al., 2020 • Rahimi & Davoudi, 2018
Section 5: Policy for EVs in Disasters		
Summary	**Sources***	
5) Policy for EVs in Disasters: Overview of existing work on policies that bolster EV resilience in disasters *8 sources*	• Li et al., 2021b • Marami Dizaji et al., 2019 • Zhang & Zhang, 2022 • Ku et al., 2021	• Lin et al., 2022 • Purba et al., 2022 • Johnson et al., 2022 • Macdonald et al., 2021

* Some sources are cited in more than one topical area

3. REVIEW OF EV CHALLENGES IN DISASTERS

Disasters can have widespread impacts on the power grid and related infrastructure, which can lead to power outages and reduce EV usability. This is particularly important since EVs tend to have shorter driving ranges than ICE vehicles, which could alter how EV owners evacuate (Adderly et al., 2018). If grids do not adapt, evacuating EVs during disasters may become more difficult as adoption grows (Macdonald et al., 2021). Additionally, increased EV adoption can lead to stress on the power grid before, during, and after disasters. Research has found that an evacuation at 20% EV market penetration could cause dynamic and severe stress on the grid during a disaster such as wildfires, which can be further modulated by location and electric load within a region (Donaldson et al., 2022). The high demand for EV charging can negatively impact infrastructure, particularly transformers. This grid component can be excessively strained and potentially fail under emergency conditions, requiring demand response strategies to decrease these occurrences (Razeghi et al., 2021).

As electric storage systems (ESSs), the operation of EVs is limited by the capacity of their batteries and the insufficient coverage of the existing charging network (Rahimi & Davoudi, 2018). Sparse charging networks remain major obstacles to EV adoption, and their unreliability could significantly challenge EV-based evacuations. With charging networks often left out of evacuation route planning, little consideration is given to EVs when planning for evacuations (Purba et al., 2022). This may render EV users unable to follow the same evacuation plans set up primarily for gas-powered vehicles (Adderly et al., 2018). Moreover, the potential for flow bottlenecks at charging stations, resulting from EVs' longer refueling time, may require active oversight and the selection of charging station locations based on a variety of considerations, including traffic and population density (Li et al., 2022b), and not just operator profits. Consequently, adequate charging coverage may be lacking in certain disaster-stricken areas, which can lead to poor evacuation outcomes. However, the rapid and continuous improvement of driving ranges, the expansion of charging networks, and the reduction of charging times for EVs may reduce the disparity between EV and ICE vehicle operations during disasters. As the share of EV sales continues to grow, some challenges may be addressed in the near future, especially with expanded EV infrastructure.

Beyond initial effects, the mass evacuation of EVs can have long-term impacts on the grid. Feng et al. (2020) conducted research on evacuations during Hurricane Irma in Florida assuming an EV-majority fleet of evacuees. The study found that crucial refuelling stations and the larger electrical grid outside of highly urbanized areas would not be able to support evacuating EVs, especially those that stop to recharge. In addition to the demand EVs will have on the network, traffic from all evacuating motor vehicles can impede the mobility of EV MPSs. As such, the transport and power networks are highly interdependent and disruptions in one can cascade and adversely impact the other (Hussain & Musilek, 2022).

Natural disasters may also cause failure in transmission devices, increasing the scale of power required and negatively impacting those residing within the impacted area (Maharajan et al., 2015). Communication infrastructure, control, and management strategies for EV discharge back into the grid are all key factors that must be considered in future strategies (Momen et al., 2020). The implementation of grid resilience strategies utilizing EVs should also ensure that the lifespan of these vehicles is unaffected by their use as electricity storage and transmission devices (Hussain & Musilek, 2022).

3.1) Key Takeaways

The increasing interdependence of electrified transportation and power networks highlights the need for disaster preparedness strategies that incorporate EVs. Limited driving range, sparse charging networks, and the strain on power grids pose challenges to EV evacuations during disasters. High EV penetration can exacerbate stress on the grid during evacuations, especially in disaster-prone areas. Additionally, infrastructure failures and bottlenecks at charging stations, such as transformer overloads, could further hinder evacuations. Adapting EV infrastructure for these scenarios, along with improvements in charging networks and driving ranges, could mitigate these interconnected issues and ensure smoother evacuations.

4. REVIEW OF EV BENEFITS AND POSSIBLE STRATEGIES

This section will discuss the unique benefits of EVs in disasters and address approaches to remedy the aforementioned challenges. The four subsections include different groupings of strategies for leveraging EVs in disasters around four topics, which could be implemented separately and concurrently. This section contrasts with the limitations of EVs in Section 3 and precedes the policy implementation in Section 5. It should be noted that the majority of literature on EVs in disasters has focused on strategy development.

4.1 Charging Infrastructure and Vehicle-to-Grid (V2G) Technology

Fast charging stations are instrumental in providing resilience to the grid during outages. Known as Level 3 chargers, they can supply high-voltage electricity unlike Level 1 and 2 chargers which are typically used for charging EVs at home (ChargeHub, 2023). Using these charging stations, vehicles equipped with bidirectional charging technology can send power back to the grid (Rahimi & Davoudi, 2018). This capability can also be provided in the form of a converter supplied at a station or installed in a home.

Since charging infrastructure is vital for EV operation, research continues to focus on ensuring EVs have access to chargers during and after disasters (Purba et al., 2023). Placement and maintenance of charging stations should minimize the impact of natural disasters while maximizing charging convenience – an umbrella term that encapsulates factors such as EV battery capacities, range, and penetration with traffic demand (Zhang et al., 2022b). For operation during natural disasters and peak-price hours, ESSs in the form of batteries may be utilized in fast charging stations. The capacity of these storage systems can be determined by the number, mileage, and arrival time of EVs as well as the amount of energy needed to charge each vehicle (Hussain et al., 2020). This information, coupled with the characteristics needed to study EV owner behavior (vehicle location, charge level, occupancy, return time etc.) can be used to provide a comprehensive, real-life study of resilience and evacuations (Liu et al., 2023b; Hussain & Kim, 2021).

Even when charging stations remain operational throughout a disaster, non-standardized charging ports can impede access for some EVs. Standardization of charging port infrastructure to ensure maximum interoperability is therefore essential (Hussain & Musilek, 2022), and highly connected to advances in vehicle-to-grid (V2G) technology. Regulatory measures can prioritize the standardization of charging ports and mandate the inclusion of V2G technology, better integrating EVs into grid operations (Razeghi et al., 2021).

V2G is a critical component in connecting EVs into the broader energy grid. V2G enables bidirectional power flow between EVs and the grid, allowing EVs to supply power back to the grid during peak demand periods or outages (Rahimi & Davoudi, 2018). This capability is already being used by manufacturers to advertise EVs. For example, the Ford Motor Company's 2023 F-150 Lightning electric truck can power a home for up to ten days during outages using the Ford Charge Station Pro (Ford, 2023). This shows the potential for EVs to serve as mobile energy storage units. Research suggests that V2G systems can be improved with three-level converters, which can further improve bidirectional power flow, increasing transmission rates and efficiency (Yamane et al., 2019). This will enable EVs to charge and discharge at higher speeds, further boosting their resilience during disasters. V2G technology also plays a pivotal role during natural disasters and emergencies. By enabling EVs to supply power back to the grid, V2G can help maintain essential services and infrastructure during outages. For instance, EVs can be dispatched to restore critical loads at hospitals, waste treatment plants, and emergency response centers (Yang et al., 2019a).

Various approaches exist regarding when and where V2G technologies should be implemented to maximize EV power supply for outages and emergencies. One simulated approach placed bidirectional EV charging equipment in parking lots near residential or commercial districts, serving as gathering points and V2G connection points (Abdubannaev et al., 2021). These substations can be coupled with other power sources such as photovoltaic and diesel generators to supply additional power (Momen et al., 2021). Charging and discharging may also help avoid excessive demand from the grid during peak usage hours (Alizadeh and Jafari-Nokandi, 2023). Research by Yamagata et al. (2013) built a simulation to model parked EVs in central Tokyo which uses EVs to store photovoltaic energy in a bid to minimize the effects of an outage and provide the optimal amount of power to the area. These vehicles can also be deployed to supply power to other islanded microgrids if needed (Ali et al., 2020).

Despite the benefits of these technologies, V2G and fast charging measures may face challenges that limit their effective implementation in emergencies and evacuations. Battery degradation, mainly due to excess heat generated from fast charging, can potentially shorten the lifespan of EV batteries. In addition, current infrastructure may struggle to support the high-power demands of fast charging stations, especially when equipped with V2G technology (Hasan et al., 2021). Addressing these challenges such as through advanced thermal management, optimized charging algorithms, and demand response systems may help increase V2G resilience in a disaster.

4.1.1 Key Takeaways

Fast charging stations are critical for resilience since they enable EVs to both charge quickly during urgent evacuations and send electricity back to the grid during power outages. Proper placement, standardization, and maintenance of all charging stations should be considered for disaster preparedness and evacuation. For the latter bidirectional strategy, V2G technology plays a key role, allowing EVs to function as mobile energy storage units and supply power to critical infrastructure or devices during outages. Further research will be needed within these topics to improve bidirectional power flow, enhance system efficiency, factor in battery degradation, and optimally place charging stations for evacuations.

4.2 Pre-Disaster Measures

Recent research has begun to identify pre-disaster measures that can reduce electricity demand, ready EVs, and/or conduct transportation responses. For example, research has identified how maximizing energy stored within both EVs and gas-powered vehicles prior to a disaster can help improve resilience (Gazijahani et al., 2022). Load curtailment is commonly suggested as a means of usage control and preventing total loss of power. This entails limiting or entirely cutting the supply of power to non-essential purposes. Load curtailment can also be administered during outages in order to manage demand (Gazijahani et al, 2022; Candan et al., 2023) by categorizing loads into different classes. Despite the benefit of managing electric usage, load curtailment can be expensive as special equipment is required to implement the approach, which can lead to reduced productivity (Tian & Talebizadehsardari, 2021). Along with pre-charging and curtailment, EVs can be prepositioned at crucial locations along the grid in anticipation of damage (Lei et al., 2019). Early and rapid dispatch of EVs can help keep essential infrastructure functional (e.g., medical equipment). During the recovery period, organized and optimized dispatch can help minimize operational costs (Yang et al., 2020a).

Research has also found that mandatory and voluntary evacuation orders may require retooling when considering EVs, the grid, and congestion. Work by Erenoğlu et al. (2023) compared the rates of load restoration by dispatching EVs to microgrids in need while considering traffic congestion. Results found that the restoration rate was hampered by congestion, highlighting the importance of traffic considerations in planning power restoration to the grid. For coordination, research has suggested the development of a mobile application that would allow EV owners to input their desired evacuation time window (Li et al., 2022b).

In addition to evacuation orders, educational measures with information on optimal practices can help prepare the public to conduct successful evacuations with EVs. One such practice is to refrain from fully charging EV vehicles during evacuations. Feng et al. (2020) found that Florida's current electrical grid could handle the increased load from evacuating EVs if drivers only partially charged their vehicles. Studies have also found that routinely maintaining a state-of-charge (SoC) of 20-80% is best for minimizing outages, but in practice, drivers may operate their vehicles outside of this range (Donaldson et al., 2022). The effective implementation of V2G technology is also contingent on the rapid response of willing participants which may vary based on factors such as weather conditions at the time of the disaster (Wu et al., 2022, Liu et al., 2023b). As such, EV drivers in disaster-prone regions may benefit from advanced information on charging procedures to help prevent outages and conduct safe evacuations within their regions.

4.2.1 Key Takeaways

Research suggests that pre-disaster measures such as maximizing stored energy in EVs and using load curtailment can improve grid resilience. Load curtailment manages demand by limiting non-essential power usage, though it can be costly. Prepositioning EVs at key locations along the grid can also help maintain essential infrastructure. Evacuation planning will need to account for EVs, grid capacity, and congestion, as delays in EV dispatch can slow power restoration. Preparedness measures such as advising EV drivers to pre-charge before evacuations and maintain a 20-80% state of charge could help prevent outages while still ensuring EV usability.

4.3 Microgrids & EV Power Supply

Microgrids and EV power supply are extensively covered topics in research sources that consider resilience and EVs. A microgrid is a small grid that can sustain and manage its own electricity supply and demand within a region (Gouveia et al., 2013; Gholami et al., 2016). Microgrids can operate in either grid-connected or islanded modes. Grid-connected or networked microgrids can connect to and exchange with the larger grid or other microgrids within a community to improve overall system performance (Ali et al., 2020). In a related way, islanded microgrids can operate independently of the wider network during disasters and provide electricity within their own grid (Alizadeh & Jafari-Nokandi, 2023). Importantly, a microgrid drawing power from microturbines, wind turbines, and energy storage systems in addition to EVs can produce enough power to be self-sustaining (Marami Dizaji et al., 2019). ESSs can also enhance the operation of a microgrid by storing excess energy during normal conditions or periods of low demand, which can then be returned to the grid during a disaster or high-demand periods (Gouveia et al., 2013). It should be noted that microgrids and V2G are somewhat different concepts, though with overlap. Microgrids best describe the specific infrastructure or resources (i.e., interconnected loads) that can act together to provide power (whether connected or islanded from the main grid). V2G refers to the specific technology and operations that allow electric vehicles to connect to the grid (whether main or micro). Importantly, V2G can enable an EV to connect to a microgrid as a resource.

The operation of microgrids can be beneficial during both emergencies and normal periods (Razeghi et al., 2021). Under normal grid operation, EV owners can be incentivized to return power back to the grid using monetary compensation, thereby increasing supply and balancing peak demand periods (Hasan et al., 2021; Hussain & Musilek, 2022). Management of microgrids during emergencies can be divided into two categories. Here-and-now decisions consider the current state of microgrids and the distribution network for decision making, while wait-and-see decisions are based on the real-time operation of microgrids considering uncertainties such as natural disasters (Ebadat-Parast et al., 2022; Gholami et al., 2016; Momen et al., 2021). Rigorous modelling of microgrids with uncertainties can help inform the desired operation of microgrids during disasters (Gholami et al., 2016).

Ideally, microgrids would draw from zero-emission power sources and enhance resilience by supplying the electricity demand of the community during disasters (Simental et al., 2022), though the use of back-up diesel-fuel generators often provides sufficient power during disasters (Ding et al., 2020). Research also suggests that EVs can also help regulate the local grid, voltage control, and system reliability (Momen et al., 2020).

Microgrids can be supplemented with other technology to help bolster performance. A soft open point (SOP) can help rapidly isolate faults in networked microgrids and manage individual microgrid operations based on demand (Ding et al., 2020). Post-disaster, a grid can be broken up into multiple microgrids using sectionalizers, allowing easier service by EVs (Yadav et al., 2021). Furthermore, electricity supply can suffer from fluctuations and interruptions during disasters. This can be remedied through the use of EVs and PHEVs to generate and store power in a store-carry-forward scheme that aims to balance supply and demand (Yamamura & Miwa, 2014).

More closely related to EV power supply, EV clusters have also been suggested to restore and maintain electricity infrastructure such as substation transformers (Hussain & Musilek, 2022). An on-call fleet of EVs has been suggested for this specific purpose as well, where vehicles are assessed based on their location and state of energy (SoE) and dispatched to critical locations during emergencies (Erenoglu et al., 2022).

4.3.1 Key Takeaways

EV power supply is key to enhancing resilience during disasters, especially within the context of microgrids. Microgrids can operate either connected to the larger grid or in isolation and can receive power from EVs via V2G technology. EVs owners, especially when incentivized, can help balance supply and demand to help manage microgrids during emergencies. Other technologies, such as soft open points and EV clusters, can improve fault isolation and electricity restoration during disasters.

4.4 Auxiliary Power Sources: Supplements and Alternatives to EV Power

In this section, we provide an overview of power sources that can be used in tandem with or in place of EVs to help meet electricity needs during emergencies. Supplements include stationary sources (e.g., generators, batteries) and mobile sources (e.g., electric buses, hydrogen fuel cell vehicles, and plug-in hybrid electric vehicles).

4.4.1 Generators and Batteries

In addition to EVs themselves, vehicles equipped with diesel generators or high-capacity batteries have been studied to help meet electricity demand (Ding et al., 2020; Gao et al., 2017; Momen et al., 2021). These vehicles are collectively known as mobile battery-carried vehicles (MBCVs) (Ding et al., 2020). Repurposed EV batteries can be utilized by mobile charging units as well as in stationary use cases such as ESSs as a backup source of power during disasters. Second-use batteries can come from EVs that suffer mechanical failures or crashes (Moore et al., 2020). They can also be sourced from battery swapping stations (BSSs), which are facilities used to swap depleted EV batteries with charged ones. Recently, BSSs have been studied to function as large electricity reserves for use in outages (Guo et al., 2021).

Photovoltaic generators (PVs) are another source of power that can be used alongside EVs. The combination of these two energy sources has been the subject of several studies. Simental et al. (2022) conducted a study on the cities of El Paso in Texas as well as Las Cruces and Holloman in New Mexico and determined that a combined EV/PV system used during a one-day outage during a summer heatwave can fully supply these areas with their electricity needs. Saitoh et al. (2013) proposed the creation of an islanded microgrid where small, distributed generators (DGs) such as EVs and PVs contributed to the operation of a functioning microgrid.

While PVs could increase the available energy and resilience of the grid, they also present challenges (e.g., voltage fluctuation). Smart inverters could resolve this issue by controlling voltage, but deployment can be expensive (Yadav et al., 2023). A virtual power plant – or VPP – can also be used to manage outages caused by disasters, whereby supply and demand for power are managed by a cloud-based software that dispatches EVs to actively help bolster the electricity needs of part of the community (Liu et al., 2023a; Maharjan et al., 2015). Since microgrid management by VPPs requires the active movement of EVs, traffic between two microgrids must be taken into consideration (Liu et al., 2023a).

4.4.2 Electric Buses (EBs)

Alongside generators and batteries, other vehicle types could act as additional (or alternative) sources of power and transportation. The most readily available example is battery electric buses (EBs), which have gained popularity at many public transit agencies worldwide. EBs can play vital roles during disasters (e.g., evacuating residents, powering essential resources), though challenges exist related to battery range, charging speeds, and infrastructure. One key advantage of electric buses (EBs) in disasters over EVs is that buses can transport more individuals during an evacuation, significantly reducing grid demand (Zhang & Zhang, 2022) and congestion. When not used for evacuations, research has suggested that buses can help grid resilience (Li et al., 2022a). For example, EBs could be connected to the grid at charging stations, acting as either storage systems or power sources depending on the circumstance (Li et al., 2021a). Work by Tessler & Traut (2022) found that effective electric emergency operations require resilient but cost-efficient charging infrastructure.

Scheduling EBs for emergency power supply and transit comes with challenges, including the need for timely updates on road conditions and access to charging stations equipped with V2G technology. Cost efficiency is another challenge, which can be optimized by comparing the cost of transportation with the benefit of critical load supply at any given station (Gao et al., 2017). The cost-effectiveness of electric bus operations depends on the size of the fleet as well as the frequency and severity of the disaster (Li et al., 2022a). Three-level converters could be highly useful in discharging EBs since they allow for power to be transmitted from the battery at a much higher speed (Sayed & Gabbar, 2016). In addition, electric buses' primary objective is to transport people, which may be limited in certain disasters given the limited range and available charging infrastructure of these buses. An optimization plan can help in this regard by minimizing total travel time while accounting for vulnerable populations (Zhang & Zhang, 2022). Another limitation of the primary function of EBs as public transport vehicles is balancing their role as people movers versus power sources. EBs in a public transport fleet will likely be required to operate continuously throughout a disaster with little downtime. This could leave small or negligible windows for their use as power sources. The practicality of using EBs for power generation while considering operations is generally absent from the literature, warranting the need for further studies on their feasibility.

4.4.3 Hydrogen Fuel Cell & Hybrid Vehicles

Switching to different combinations of fuel sources and power generation compared to EVs and EBs, hydrogen fuel cell vehicles (HFCVs) operate using electric motors but benefit from faster, grid-independent refueling using compressed hydrogen (Dong et al., 2023). To ensure sufficient fuel, mobile hydrogen energy resources (MHERs) can be dispatched to refuel hydrogen distribution systems (Cao et al., 2023). Research suggests that hydrogen-powered buses and cars could provide power generation during outages using their electric motors (Dong et al., 2023).

PHEVs have also been studied as potential opportunities for power and transportation during disasters. PHEVs use fossil fuels for their ICE, which operates in tandem with and recharges an electric motor. These vehicles can achieve ranges higher than that of traditional combustion engine vehicles (Abessi et al., 2020). Despite their range, PHEV electric components are smaller and less capable than full EVs, which reduces their effectiveness when supplying power (Rahimi & Davoudi, 2018). This further necessitates the use of sources such as solar panels and generators in addition to a PHEV (Abessi et al., 2020).

4.4.4 Key Takeaways

Generators, batteries, electric buses, and hydrogen fuel cell vehicles offer alternative and supplementary options for EV power generation. Mobile battery-carrying vehicles equipped with diesel generators or high-capacity batteries can help meet electricity needs, while repurposed and recycled EV batteries can serve as energy reserves at residences or businesses. Photovoltaic generators can complement EVs in providing energy, though they present challenges including voltage fluctuations that require management via smart inverters. Electric buses, which are gaining popularity, play a role in both evacuating residents and contributing to grid resilience by acting as temporary power sources. Hydrogen fuel cell vehicles and plug-in hybrid electric vehicles offer additional options for evacuation and resilience. However, limitations such as battery range, infrastructure, and cost-efficiency present challenges to using these sources effectively during disasters.

5. POLICY FOR EVS IN DISASTERS

Adequate adoption and use of EVs in disaster scenarios require effective policies that compel users to participate in employing EVs to contribute to community resilience. To increase control over charging and discharging times, time-of-use (TOU) prices could be introduced that further push consumers to recharge their vehicles at lower demand periods (Li et al., 2021b). The study simulated a charge/discharge scheduling process where EVs could be timed to dispatch power back to the grid, finding that this policy (with proper compensation) could help increase grid resilience (Li et al., 2021b). For microgrid operations, shifting power consumption to align with low market prices can help the microgrids reduce the cost of energy (Marami Dizaji et al., 2019), especially in brownouts and rolling blackouts. Leveraging a demand response program, energy storage units, and EVs, the operational cost of the microgrid can be reduced while still retaining resilience in an uncertain island mode (Marami Dizaji et al., 2019). In both of these two policy cases, demand response and effective scheduling of EVs play a key role in resilience, indicating the need for close collaboration among government agencies, utilities, and EV owners.

Policies should also consider equity for populations most vulnerable to natural disasters and their effects. Research has found that waiting times at assembly points and the severity of the impact of electricity deprivation differ from one community to another (Zhang & Zhang, 2022). For more equitable transit-based evacuation planning and policy that help reduce differences in wait and movement times, Zhang and Zhang (2022) found that a sufficient supply of charging stations is critical in their modelling approach, along with a routing plan that pushes EBs closer to their maximum range. For powering EBs, Ku et al. (2021) suggest that rooftop solar could be added to residences along environmentally burdened bus routes (identified via an environmental justice index), allowing underserved populations to sell power and reduce air pollution. Underserved areas can then form their own community-owned blocks of electricity generation which can increase local resilience (Ku et al., 2021), similar to microgrids. While proposed approaches such as rooftop solar, renewable household generators, and EV ownership would help reduce both utility bills and carbon footprints, many approaches are unattainable for low-income households, which are often most severely affected by natural disasters (Lin et al., 2022). An equity-driven framework for pre-event and emergency response planning could assist decision-makers, helping prioritize electricity to underserved populations, ensuring sufficient resilient hardening across the system, and restoring power to minimize disparities (Lin et al., 2022).

A lack of knowledge surrounding EVs and their required infrastructure also exists for evacuations. To resolve this, research indicates that tools and guidelines could be developed for different officials and coordinators that help direct a safe and smooth evacuation process for EVs (Purba et al., 2022). For example for routing EVs, Purba et al. (2022) suggest that a hop constraint could account for driving range variability, determine feasible routes, and guarantee charging access. To complement this policy, the research indicates that both higher density and strategic locations of charging infrastructure would significantly improve evacuation performance, especially for lower-range EVs. In practice, Johnson et al. (2022) proposed several measures and tools in the Florida Alternative Transportation Fuel Resilience Plan for most types of vehicle fuels. After engagement with over 240 officials and affected parties, three tools were developed to help locate emergency facilities throughout the state, provide communication between EV supply equipment (EVSE) and emergency personnel, and plan possible evacuation strategies. The plan also provided an analysis of the coverage of both existing alternative fuel stations and proposed stations across evacuation routes in Florida (Johnson et al., 2022). The further development of these tools will be critical for practically assessing existing EV resilience and indicating needed changes in infrastructure, evacuation routes, and preparedness education. In the Canadian context, Macdonald et al. (2021) simulated evacuations from Prince George, British Columbia, finding that existing infrastructure would not meet EV demand and queues would be long at charging stations. Similar to the Florida plan, the study concluded that policymakers could increase the capacity and density of charging stations to help meet EV demand during the evacuation. Earlier evacuation notices and more public Level 3 chargers would also significantly help EVs in evacuations (Macdonald et al. 2021).

5.1 Key Takeaways

Overall, current research is starting to develop new policy ideas for EVs in disaster scenarios, specifically demand response programs (for outages), equity-centered strategies for electric bus scheduling and charging, feasible EV routing tools, and upgraded and optimally located charging infrastructure for EVs in evacuations. These studies collectively underline the importance of policies that specifically address economic, social, and infrastructural aspects to ensure effective and equitable adoption of EVs in emergencies. Despite these opportunities, the translation of policy-driven research into implementable action remains missing, beyond a few examples. Moreover, most research remains simulation-based without focusing on data from EVs or EV owners. This creates a possible disconnect, one where policy recommendations from academic research may not meet the direct needs of evacuees. Finally, little information exists on the state of evacuation planning with the consideration of EVs, based on our review. Future work will be required to set this context through a review of existing emergency response and evacuation plans.

6. DISCUSSION

The goal of this research was to provide an early understanding of the state of research on EVs, resilience, and evacuations by identifying and analyzing relevant literature. This section will discuss each segment and highlight key takeaways relevant to the research questions.

6.1 Overcoming EV Deficits

The review found that EVs face multiple challenges stemming from their unique fuel source and refueling mechanism. Of all these obstacles, resolving charging station congestion received some of the least attention in the literature on the subject. At the same time, only a few studies focused on the evacuation of EVs (e.g., Feng et al., 2020; Li et al., 2022b; Purba et al., 2022). Despite this, the overarching problem of long charging times remains a key challenge that will require significant research from simulated *and* real-world cases.

In addition to charging time, the limited capacity of batteries also points to an understudied area of research. This is especially critical for longer-length power outages or large-scale disasters. While increasing the density of the charging network helps mitigate the short range of EVs, research on methods to extend the range of EVs as a case for disaster resilience is rare. Frequent stops for refueling could hinder evacuations and recovery processes, including for maintenance fleets. Novel methods of recharging vehicles such as electrified road segments and inductive charging are also notably missing from our review. Moreover, technological and economic progress in batteries is still required to meet (and eventually succeed) the driving range and energy storage of vehicles with an ICE.

Studies also tend to overlook the length of power outages. EVs will be unable to provide power throughout an extended power outage, essentially delaying the inevitable loss of power for the user. While the usage of other sources of power alongside EVs is often suggested (Abessi et al., 2020; Sayed & Gabbar, 2016; Momen et al., 2021; Yadav et al., 2021), these recommendations depend on the interconnection of users to a larger grid. This leaves out those who cannot or choose not to connect to a larger network, such as those living in remote or rural locations. Within this general issue, ongoing public safety power shutoff (PSPS) events in California could cause additional challenges, especially as these pre-planned shutoffs could reduce EV travel. Research has found that power loss is an influence on some travel behavior (Wong et al., 2022).

The upfront cost of EV resilience measures and infrastructure is not sufficiently discussed, and very few papers mention end-user cost as a consideration (Hussain & Musilek, 2022; Zhang et al., 2022b). EVs are generally more expensive than gas-powered cars, and the infrastructure and resources needed to take full advantage of their resilient capabilities during disasters require investments that many drivers may not be able to justify. Future research can investigate methods to provide essential resilience components that are more affordable and accessible.

6.2 Building Realistic Strategies

The potential for EVs to aid in evacuations and disaster scenarios is covered well by research in this review. This indicates that opportunities do exist for smart and effective utilization of EVs during disasters. However, a large portion of the analyzed research focuses on grid resilience, while incorporating the auxiliary use of EVs (Wu et al., 2022; Ebadat-Parast et al, 2022; Momen et al., 2021; Ding et al., 2020). Consequently, grid resilience is elevated above transportation and EV resilience. As a result, more focus is put on the use of EVs as an on-call fleet to power the larger grid, leaving opportunities for future research to study options that focus more on EV users and their choice. Similarly, EBs are often viewed as on-demand power sources without considering their primary function as transportation vehicles, and little research addresses alternatives to municipal buses, such as school buses (Karan, 2024). Additionally, while some papers suggest a grouping of vehicles could be used to supply power (Cao et al., 2023; Hussain & Musilek, 2022; Yamagata et al., 2013), most research solutions do not study the number of vehicles needed to achieve the intended results. Since different actions and energy demands require varying numbers of EVs, further research can be conducted to study optimal strategies for different EV adoption patterns and fleet mix.

Resilience strategies are often not discussed within research on charging infrastructure or operations. Studies place a strong emphasis on the continued operation of charging stations throughout disasters (Purba et al., 2023; Tessler & Traut, 2022; Zhang et al., 2022b), but strategies for their continued operation seldom extend beyond their strategic placement to reduce the likelihood of damage. This can conflict with planning that emphasizes charging station accessibility during disasters. As such, there is room for future research to further study all facets of charging infrastructure placement and to develop independent solutions to ensure charging stations continue to provide service to EV users.

Importantly, our review found that user behavior is highly understudied in EV research on evacuations. While several papers advocate for improving EV technology and increasing charging infrastructure density to accommodate all possible EV user actions (Adderly et al., 2018; Feng et al., 2020; Purba et al., 2022), other work focuses on directing user behavior in line with optimal outcomes and performance (Zhang & Zhang, 2022; Li et al., 2022b). In both cases, EV driver behavior is left out, widening the research gap on EV resilience in critical scenarios. Few papers cover EV driver choices and willingness to participate in demand response events related to hazards (Donaldson et al., 2022; Liu et al., 2023b). The participation of resident-owned EV fleets is more difficult to coordinate and more heavily relies on the willingness of users to partake in the proposed measures. This includes challenges related to demand response programs that can shift electricity demand (e.g., smart charging). While smart charging programs can be useful in disaster events, they require sufficient consumer opt-in and are affected by the program design and demographic characteristics (Wong et al., 2023). Future research can focus on the behavior of individual EV users to further optimize the better align societal goals, driver actions, and infrastructure.

Finally, despite the availability of EV technology for analysis (especially in the last five years), our review found minimal evidence of real-world experiments, data, or observations of EVs in disasters and evacuations. Anecdotal evidence is also largely missing from the literature, which can inhibit policy implementation and reduce the sharing of lessons learned. Testing EV strategies in real-life demonstrations or collecting data directly from EV drivers or auto companies will help future research uncover technical or logistical problems that may not come up in theory or simulated methods.

6.3 Understanding EV Resilience Across Disaster Phases

This section of the discussion revisits the state of current research on EV resilience during disasters from a disaster response standpoint. While valuable work has been completed to assess various aspects of EV evacuations and emergency use cases, our review found that some of the four stages of the disaster response process—mitigation, preparedness, response, and recovery—have received more attention than others. As demonstrated in Table 1, of the 61 peer-reviewed sources cited in this paper, 15 focus on mitigation, 25 on preparedness, 9 on response, and 7 on recovery. A total of 5 articles were also identified that broadly touch upon each of the four steps in some capacity. This research imbalance hints at a focus on theoretical and technical applications of EVs and complimentary energy supply and storage devices as alternate power sources, leaving room for further research on the practicality of these solutions throughout the entire recovery phase as communities await the restoration of electric services. While some research investigates how long EVs can be used to help sustain power to communities (Simental et al., 2022; Hasan et al., 2021), most are more limited in their scope and discuss the feasibility of implementing a proposed solution rather than the longevity of said solutions and the extent to which they can service the target population. Resilient disaster planning requires a complete view of an emergency and sufficient attention to all stages of the disaster cycle. Future research can aim to rebalance this focus by prioritizing response and recovery strategies and their implementation to ensure adequate preparation for these extraordinary circumstances.

Table 2. *Peer-Reviewed Sources Grouped Based on Disaster Phase Focus*

Disaster Phase Covered	**Topic**	**Sources**	**Summary and Focus**
Mitigation *15 sources*	Using EVs to meet emergency energy needs	• Ali et al., 2020 • Alizadeh & Nokandi 2023 • Gouveia et al., 2013 • Hussain & Musilek, 2022 • Liu et al., 2023a • Moore et al., 2020 • Rahimi & Davoudi, 2018 • Saitoh et al., 2013 • Yadav et al., 2023	Technical aspects of using EVs to supplement existing energy infrastructure, from mobile energy storage devices to primary sources of power. The research in this section focuses on using EVs to prevent and mitigate power shortages during a disaster.
	Pre-disaster planning	• Ebadat-Parast et al., 2022 • Gholami et al., 2016 • Wu et al., 2022	Planning, resource allocation, and scheduling of EV charging before a disaster occurs to prevent catastrophic outages.
	Charging infrastructure density and placement	• Adderly et al., 2018 • Hussain et al., 2022 • Purba et al., 2023	Expanding the existing charging infrastructure to address issues arising from limited EV range.
Preparedness *25 sources*	Evacuation planning and modeling	• Donaldson et al., 2020 • Donaldson et al., 2022 • Feng et al., 2020 • Li et al., 2022b • Macdonald et al., 2021 • Purba et al., 2022	Assessing the impacts of EVs in an evacuation to identify potential challenges and plan for evacuations with these vehicles. This includes exploring hindrances and controlling congestion both pre- and post-departure.
	Bolstering infrastructure resilience	• Lei et al., 2019 • Momen et al., 2020 • Sayed & Gabbar, 2016 • Yadav et al., 2021 • Yamane et al., 2019 • Yang et al., 2019b • Yang et al., 2020b • Zhang et al., 2022b	Preparing EVs, charging stations, and other infrastructure involved in fueling EVs for an imminent emergency scenario such as flooding or fires. The goal is to ensure crucial infrastructure remains operational throughout a disaster.
	Energy management	• Abdubanaev et al., 2021 • Cao et al., 2023 • Hussain & Kim, 2021	Developing strategies to minimize energy costs and increase energy resilience, including the impact of EVs on grid

		• Razeghi et al., 2021 • Tessler & Traut, 2022 • Tian & Talebizadehsardari, 2021 • Yamamura & Miwa, 2014	resilience and methods to incorporate EVs into grid operation procedures (such as their use as MPSs).
	Equity	• Ku et al., 2021 • Zhang & Zhang, 2022	Examining EV adoption and evacuation planning on equity, particularly in short-notice evacuations, and proposing frameworks for equitable access to electrification.
	Pre-disaster planning	• Gao et al., 2017 • Lin et al., 2022	Exploring pre-disaster resource allocation and strategies for minimizing losses during extreme outages, highlighting the importance of proactive planning and preparedness measures.
Response *9 sources*	Power restoration via EV dispatching	• Erenoglu et al., 2022 • Li et al., 2021b • Liu et al., 2023b • Yang et al., 2020a	Dispatching EVs to critical locations to restore power after the event of a disaster, particularly utilizing EVs as MPSs.
	Pre-allocating EVs	• Erenoglu et al., 2023 • Li et al., 2022a	Using EVs and electric buses in pre-deployed at critical locations to prevent extensive outages or minimize power loss.
	Other	• Abessi et al., 2020 • Ding et al., 2020 • Guo et al., 2021	Utilizing battery swapping stations, hybrid vehicles, and networked microgrids to manage electrification in response to a disaster.
Recovery *7 sources*	Utility management	• Li et al., 2021a • Marami Dizaji et al., 2019 • Momen et al., 2021 • Yang et al., 2019a	Managing outages, coordinating restoration efforts, and scheduling resources (e.g., charging price incentives, load shifting strategies).
	EV power supply	• Hasan et al., 2021 • Simental et al., 2022 • Yamagata et al., 2013	Targeting the use of EVs in disasters as a source of power, with a focus on sustained long-term power supply using EVs and auxiliary sources such as solar panels.
All Phases *5 sources*	Holistic approaches	• Candan et al., 2023 • Dong et al., 2023 • Gazijahani et al., 2022 • Johnson et al., 2022 • Maharajan et al., 2015	General approaches on the subject of EVs and hydrogen fuel-cell resilience during disasters, including microgrid integration, infrastructure flexibility, and low-carbon resilience options.

7. CONCLUSIONS

This literature review analyzed the main challenges facing the use of EVs during disaster scenarios and identified that a lack of charging infrastructure is one of the largest ongoing issues. This, coupled with the short range of EVs, was found to limit the mobility and utility of EVs in disaster scenarios. The long charging time of EVs compared to ICE vehicles can create congestion at charging stations, irregular charging patterns, and unexpected behavioural patterns. Generally, policies and planning were found to neglect EVs in disasters. Moreover, the review highlighted a lack of focus on real-world experiments and demonstrations, user behavior, and the prohibitive cost of resilience strategies. Through an analysis across disaster phases, an imbalance in research focus was also found, with more attention given to mitigation and preparedness, leaving gaps in response and recovery strategies. This imbalance indicates theoretical and technical challenges with EVs during and after disasters, indicating the need for further inquiry.

Along with these challenges, the review identified that EVs can positively act as mobile energy storage and transmission systems, especially in a power outage event. By giving equal attention to all disaster phases and strategically implementing technologies such as V2G, EVs can be used in tandem with or in place of other power generation devices to supply power to communities via microgrids and grid management. The full utilization of these capacities requires the inclusion of alternate fuel vehicles into a holistic approach to disaster management and the conscious deployment of infrastructure with these emergency scenarios in mind. In addition, EVs retain high viability in evacuations, especially if key preparedness measures are taken.

Future research in the field of EVs, resilience, and evacuations requires attention to the major limitations of EVs in emergencies and the testing of possible benefits. Key research directions based on our review include the following:

- Identify and optimize charging infrastructure placement for disaster scenarios;
- Assess EV driver behaviour, both stated and revealed, in disaster scenarios;
- Study both standalone EV resilience and their resilience as part of the wider grid;
- Conduct and/or evaluate real-world experiments on proposed strategies;
- Collect charging data and vehicle trip-making patterns from existing EVs during recent emergencies;
- Address technological barriers of EVs in disasters, especially related to driving range and charging time;
- Test the feasibility (and limits) of related V2G technology, especially in the context of microgrids and other power supplies, through the development of practical evaluation programs;
- Identify and assess case studies of EV usage in disasters; and
- Prioritize the practical application of EVs in all disaster cycle phases, with additional focus needed in response and recovery.

With both challenges and opportunities, multiple new avenues have opened for research using a variety of approaches (e.g., simulated, empirical, behavioral, etc.). As the adoption of EVs continues to rise, problem-driven research and practical evaluation of EVs can help guide the development of resilient, electrified transportation.

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