Proposal Title: Improving Preparedness of Communities for Evacuations using ZEVs
Applicant Institution: University of California, Merced
Name of Applicant Principal Investigator (PI): de Castro, Ricardo

1. Proposed Research Activities and Specific Aims

California is rapidly embracing zero emission vehicles (ZEVs) as a means to decarbonize its transportation sector. According to Executive Order N-79-20 [1], ZEVs will be the only new vehicles allowed to be sold in the state by 2035. At the same time, California is highly vulnerable to severe weather events and hazards, such as wildfires, floods, and earthquakes, which pose a significant threat to human life and property. In the past 5 years, all 58 California counties have experienced multiple disasters, with wildfires being the most common hazard [2]. It is expected that the frequency and intensity of weather events will continue to increase due to the impact of climate change [3], [4].

State and local officials often request populations to evacuate from danger areas in order to reduce loss of human life. More than 1 million people were ordered to evacuate in California between 2017-2019 due to wildfires, often with little advanced notice [5]. The evacuation strategies that our communities have relied on up to now depend on vehicles powered by fossil fuels. These vehicles can be quickly re-fueled by an abundant network of gas stations, while their long drive range of over 400 miles [6] makes them particularly valuable for short-notice evacuations. As we transition toward cleaner electric vehicles, which do not (yet) have a dense and robust re-charging network, several concerns emerge about the preparedness of our communities to effectively support short-notice evacuations using ZEVs.

Figure 1. Traffic congestion during the evacuation of Lake Tahoe triggered by Caldor Fire (Source: Josh Edelson / AFP);

Availability of charging infrastructure is one of the major concerns, not only during day-to-day operation of ZEVs, but more importantly during evacuations. For example, battery-based EVs might need a long time to recharge, especially if only slow Level 1 or 2 charging is available (up to 0.5 miles/minute [7]), which can be problematic during emergencies, where time is of the essence. Quicker charging is possible using DC charging (up to 10 miles/minute [7],[8]), but the availability of this infrastructure is still limited. For example, according to the ZEV dashboard of California Energy Commission [9], five counties in California (Alpine, Lake, Plumas, Sierra, Yuba) have no public DC fast charging as of December 2022, which might delay ZEV evacuations in these areas.

Power outages in charging stations is another key vulnerability. This loss of power might happen due to natural disasters, e.g., physical damage to the electrical generation, transmission and/or distribution network. It might also occur due to public safety power shutoffs [10], which are used by electrical utilities to reduce the risk of ignition and thus wildfires; this interruption of electricity can last for several days [11]. **What if ZEV owners are asked to evacuate quickly and need to recharge their vehicles during a blackout and/or public safety power shutoff?** If the EV charging stations (private or public) do not have backup power, these users may be stranded, compromising their safety. There is an urgent need to revisit evacuation strategies of California communities, which were originally designed around vehicles with internal combustion engines and are unprepared to cope with large-scale adoption of ZEVs. **Our aim is to develop planning, decision-aid tools and policy recommendations that can help communities and government officials in California improve their preparedness for emergency evacuations using ZEVs**. The project objectives are:

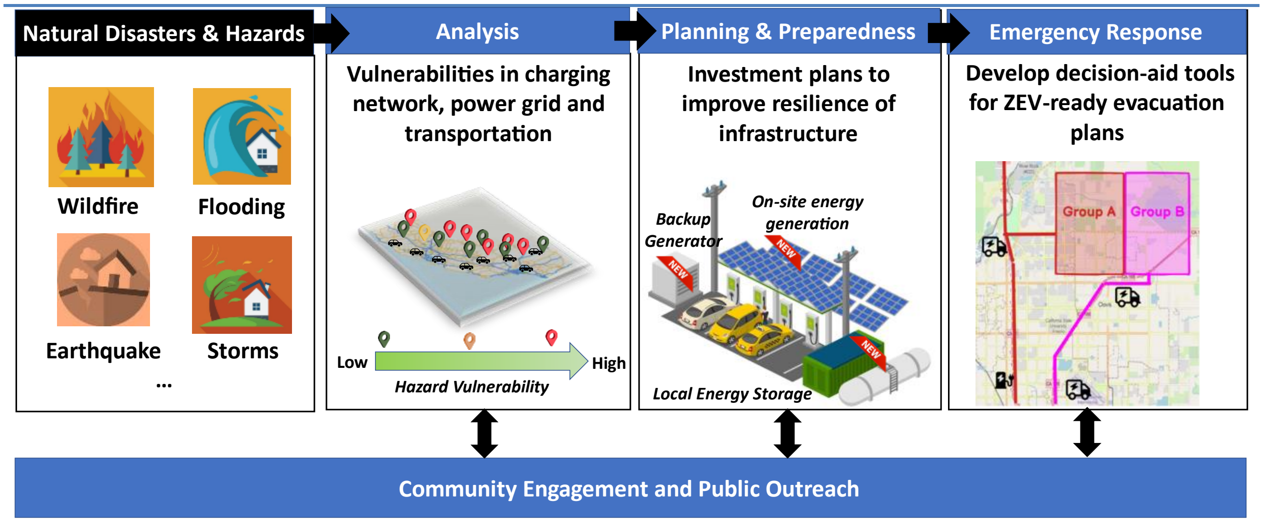

Figure 2. Overview of the key areas in ZEV evacuation.

Objective 1: Develop a *ZEV Evacuation Readiness Score* that measures the sufficiency of the existing infrastructure to support effective ZEV-based evacuations, while taking into account vulnerabilities to severe weather phenomena and natural hazards.

Objective 2: Build decision-aid tools that support stakeholders to identify affordable and effective strategic investments in power systems, charging and transportation networks that can improve the *ZEV Evacuation Readiness* score of communities. This information will be particularly useful to state and local authorities. Specifically, this tool will guide infrastructure investments that improve preparedness for ZEV evacuation in response to natural hazards and climate-related events, which are becoming more frequent in California due to climate change.

Objective 3: Devise methods to optimally place mobile EV chargers, recommend route planning and charge scheduling suitable for ZEV-based evacuations; most of today's approaches for evacuation still assume conventional gasoline vehicles, which might be impractical for ZEVs due to their long recharging times, limited driving range and sparse charging infrastructure.

Objective 4: Recommend public policies that can be adopted by local and state governments to cope with novel problems that are emerging in ZEV evacuations. This includes, for example, prioritization of emerging vehicles in the access of charging infrastructure and mandatory backup power policies in EV charging stations.

Objective 5: Disseminate tools and resources created by the project to communities in California and state agencies via education programs. This will be facilitated, in part, by the Kern County Community District (KCCD) and UCB Institute of Transportation Studies (ITS) TechTransfer [12] programs, which both provide training workshops for transportation planning agencies, cities, counties, and communities.

1.1 Research Plan and Approach

Task 1: Develop a *ZEV Evacuation Readiness Score* that measures the sufficiency of the charging, power grid and transportation networks to support effective ZEV evacuations

Multi-network evacuation problem: Emergency evacuations put stress on multiple networks of the ZEV ecosystem. We need *transportation networks* to support evacuation from dangerous zones, *a charging network* to enable re-charging ZEVs and a *power grid network* that supplies energy to the chargers. All these networks are intrinsically connected. The road infrastructure needs to be able to cope with the increased volume of traffic that emerges during short-term evacuations. Evacuees must have access to charging stations along evacuation routes to recharge their EVs before they run out of energy. And these stations need access to energy (from the grid or local energy sources) to supply the EVs. There are also other auxiliary networks, such as *payment networks* that enable users to pay for ZEV recharging. Failure in one or more of these networks, which often occurs during natural disasters, compromise safe evacuations. To effectively prepare for these emergencies, a vulnerability analysis is first required; this allows communities to better understand the systems that are at higher risk of failure and plan mitigation measures. In the literature, the vulnerability analysis of these networks is often performed in isolation; there are numerous studies that independently analyze the resilience of the *transportation* [13], [14], *charging* [15], [16] and *power grid* [17], [18] networks against climate-related events. However, there is an overall lack of a unified approach that can simultaneously integrate all these dimensions into a single framework. Our project addresses this research gap, which has both theoretical and practical value.

Exposure, Vulnerability, and Adaptive Capacity Indicators: To assess the community's ability to support ZEV evacuations, three sets of quantitative indicators will be considered. The first set of indicators focuses on hazards and exposure. We will use hazard maps [19] and local jurisdiction hazard analysis [20], [21] as sources of data for these indicators. The second set of indicators assess infrastructure vulnerability, measuring the potential for the *power grid, charging, and transportation* infrastructure to be negatively impacted by hazards. Examples of these indicators include the probability of power supply interruption [22], number of charging stations per area (or per capita/vehicle), and evacuation times. The third set of indicators will evaluate the adaptive capacity of infrastructure to respond to disruptions in charging and power grid infrastructure. Examples of these indicators include capacity metrics that measure the ability of road infrastructure to accommodate increased traffic demand during an evacuation (e.g., ability to use all lanes for evacuation regardless of their normal directional flow, parallel/redundant routes, multi-modal capabilities) and the capacity of charging stations to cope with power outages (e.g., excess capacity in generation and distribution network, onsite backup power systems and/or microgrids). Collectively, these indicators will help identify communities that are at elevated risk of climate-related events and may suffer significant damage and loss. This work builds on previous work from Co-PI Markolf exploring multi-dimensional risk propagation and resilience [23], [24].

ZEV Evacuation Readiness Score: Since the above *exposure, vulnerability, and capacity* indicators are interdependent, we will create a new aggregate metric that combines them into a single score that measure preparedness of communities to perform ZEV evacuations. This new score will be called the *ZEV evacuation readiness score* and will range from 0 (very low ZEV evacuation readiness level) to 5 (very high ZEV readiness level). It will enable state agencies and local authorities to compare the preparedness of different communities and help stakeholders understand the overall risks. It will also aid public organizations in directing technical and financial support to communities where help is needed the most. For example, communities with *ZEV evacuation readiness scores* below a specific threshold may receive "bonus points" in future grant applications for resilience investment programs in California. To calculate the *ZEV evacuation readiness score*, we will consider linear-based aggregation approaches such as weighted average of the indicators or their statistics [25]; and also analytic hierarchy processes techniques [26], [27] which allow us to assess the relative importance of different indicators.

Task 2: Develop decision-aid tools that can guide investments in charging, power system and transportation networks, improving preparedness for ZEV evacuations

Measures to mitigate vulnerabilities: Next, we will develop investment strategies to mitigate the vulnerabilities identified in Task 1. Examples of *power systems investments* include installation of decentralized energy generation (e.g., solar, wind) and storage (e.g., battery, hydrogen), which can provide power to EV charging stations when transmission and distribution lines are disrupted. Measures that make power grid components less vulnerable to natural hazards, such as protection systems and recovery strategies [28], undergrounding of power lines [29] and water-resistant infrastructures [30], will also be considered. In these times, communities may consider investments in microgrids or mobile microgrids which are exceedingly helpful during natural disasters [31]. Examples of *charging network investments* comprise installation of new (public or private) charging stations along crucial evacuation routes; and also acquisition of portable EV charging stations, which can operate off-grid and can temporarily decrease stress from stationary EV stations that are overloaded or unavailable due to damage or power outage [32], [33].

During the project execution, we will develop a comprehensive list of measures and investments that communities can adopt to reduce vulnerabilities of their ZEV ecosystem to natural hazards. This list will be based on a systematic review of the technical literature on resilient power systems, charging and transportation networks. We will rank these investments according to cost and effectiveness, and then consolidate this knowledge in factsheets, infographics, and checklists that can be easily disseminated to communities and stakeholders.

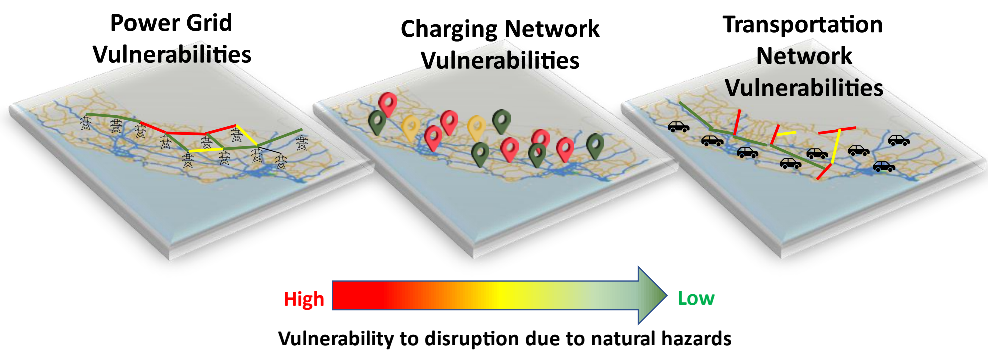

Figure 3. Illustration of some vulnerabilities in the power grid (e.g., transmission lines vulnerable to wildfire), charging (e.g., charging stations without backup power) and transportation network (e.g., communities that have a single access road to evacuate being at elevated risk of congestion during emergency evacuations).

Decision-aid tool to guide infrastructure investments: The infrastructure investments are often complex, involve multiple networks (charging, power system and transportation), with different costs and effectiveness. We will adapt approaches from multi-criteria decision analysis (MCDA) [25], [34] to develop a tool that will guide public and private entities in prioritizing their infrastructure investments. Strengths of this approach include the ability to evaluate both quantitative and qualitative data, mechanisms for soliciting input from stakeholders regarding their preferences, and the capability to conduct pairwise comparisons of different strategies and trade-offs. The tool will seek a mix of infrastructure investments that balances expected total cost, ease of implementation, and equity considerations, while improving *ZEV evacuation readiness scores*. To achieve this, decision variables such as the nature of the investment and the magnitude (e.g., sizing of the backup energy storage in a charging station and the type of backup storage) will be considered. We will also take into account uncertainty factors related to probability models of failure rates due to natural disasters and their impact on both the electrical and transportation infrastructures. This tool will build upon previous work of the research team on decision support frameworks, including, managing complexity and system interdependencies [24], [23], dealing with uncertainty in infrastructure systems [35] [36], balancing trade-offs between efficiency and resilience objectives [37], contrasting centralized and decentralized infrastructure systems [38].

Cost-Benefit Analysis and Trade-offs: The above mitigation strategies have different effectiveness and costs. For example, preventive investments, such as microgrids and decentralized energy generation are highly effective at responding to disruptions in power supply [39], but usually require costly infrastructure updates. This might be unattractive to electrical utilities or private companies, who currently manage a substantial portion of the charging network. On the other hand, prioritizing corrective investments in the form of portable EV charging might reduce upfront infrastructure costs (since they do not need expensive grid upgrades), but be less effective during emergency evacuations because extra time is needed to transport the station to a suitable location, potentially increasing evacuation time. What could be a good trade-off between preventive and corrective investments? And between private and public investments? To address these questions, we will perform sensitivity studies which could help stakeholders gain insights into the cost-benefits tradeoff of the different investments. The analysis will also inform governments and local authorities of the potential for public-private partnerships that can be exploited to reduce vulnerabilities that ZEVs might face during evacuations.

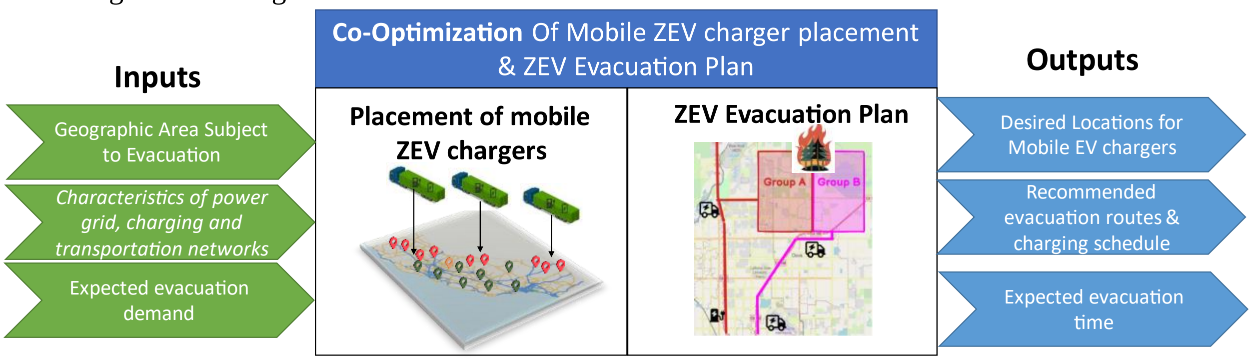

Figure 4. Block diagram of the co-optimization problem to simultaneously place mobile ZEV chargers and plan emergency routes/charging (Task 3).

Task 3: Devise methods to optimally place mobile EV chargers, recommend route planning and charge scheduling to reduce ZEV evacuation time

The strategic deployment of mobile chargers is a crucial measure to improve ZEV evacuation readiness during emergencies. This approach can alleviate the load on existing chargers, especially those located along key routes. Additionally, mobile chargers can support communities that lack (fast) charging stations. Planning the evacuation route and scheduling ZEV charging (where and when to stop to recharge the ZEV?) are other key factors during emergencies. Uncoordinated ZEV evacuation can lead to congestion on the road and at charging stations, increasing departure times from danger zones. To prevent this, ZEV owners can benefit from cooperating during evacuations. Our project aims to develop tools that communities can use to facilitate this cooperation process. This task builds upon previous works that consider mobile "robo-chargers" [40], optimal routing and charging of ZEV fleets [41], and on-demand services for mobility and vehicle-to-grid services [42].

Co-optimization Planning Problem: The placement of mobile EV chargers and ZEV evacuation planning are intrinsically coupled (e.g., the location of mobile chargers will affect ZEV owner behavior and evacuation routes). Our approach will treat these two problems in an integrated manner. The optimization objectives will focus on minimizing the overall evacuation time of the community. The inputs for this plan will be comprised of the road network configuration, the availability & capacity of stationary charging stations, and deployment of mobile chargers. We will consider the evacuation demand based on the size of the population affected by the evacuation order, the ZEV penetration rate, and percentage of people that decide to evacuate (unfortunately, a large number of individuals usually do not follow evacuation orders [35]). To solve the resulting optimization problem, we will apply nested co-optimization techniques [36], [37] in which the outer level optimizes mobile EV charger placement, while the inner level will focus on the scheduling EV charging stops and routes. We will divide the evacuation areas into multiple groups based on their zip code or other geographic characteristics. Each group will be assigned a recommended route and charging schedule that will reduce evacuation time, given road congestion and charging station queue dynamics. We will additionally consider adding energy storage at charging stations, such as lithium-ion batteries, sodium-ion batteries, and/or hydrogen.

Parameterization and Visualization of ZEV evacuation plans: To enhance accessibility to our decision-aid tool, we plan to create a user-friendly web application that allows end-users to evaluate the ZEV evacuation plans interactively (Figure 5). Working in partnership with Perimeter, an industry partner in this project, we will develop interfaces to integrate our ZEV evacuation data into their existing web-based evacuation management software [43]. We anticipate two types of end-user users for the data generated by our tools: i) local authorities, such as office of emergency services in cities and counties and ii) the general population. Local authorities can interactively parameterize the evacuation problem, selecting areas for evacuation, defining number of mobile EV chargers available in the area, their capacity, maximum time for evacuation, etc. They can then learn about the best locations for deployment of the mobile EV chargers (Figure 5b). The general population can visualize recommended routes and charging stations which they can follow during evacuations (Figure 5c).

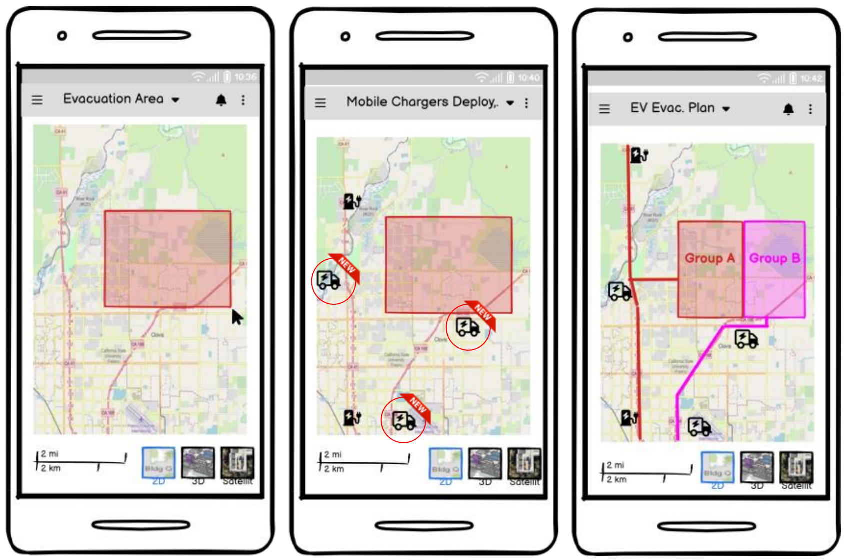

Figure 5. Mockup of the "mobile" webpage that end-users can exploit in order to visualize the ZEV evacuation plans. Left screen: selection of evacuation area; middle: suggested location for deployment of mobile EV chargers; right: evacuation routes and charging stations recommended for each evacuation group.

Vehicle-2-Grid (V2G): V2G charging offers a unique opportunity during a climate emergency. Namely, some vehicles may provisionally supply power for emergency applications. For example, a set of vehicles may move to a critical facility (e.g., hospital, school, community resilience center) and alleviate the need to start-up additional generators. Re-applying the V2G capability to a grid-forming function would allow a set of coordinated vehicles to establish a microgrid. Further, there is the possibility of direct vehicle-to-load (V2L) [44] for suppling small critical loads (communications, etc.) to responders in the area. For this project, the role of V2G will be considered in the community disaster response plan.

Pilot Test and Validation: In the last phase of the project, we will perform a pilot project with Merced and Mariposa Counties to evaluate the effectiveness of our evacuation tool. We will create a series of evacuation case studies triggered by flooding and wildfire hazards, which are top concerns in these communities. City officials and community volunteers will interact with our tool and provide feedback on ease of use; surveys will be conducted in order to understand the receptivity of these end-users to follow the recommended evacuation plans generated by our tools and resources.

Task 4: Policy recommendations to improve preparedness for ZEV evacuations

In addition to vulnerability analysis and decision-aid tools, our project will also produce policy recommendations that government agencies can consider to better prepare for ZEV evacuations. Specifically, we aim to develop a better understanding of the suite of policies and strategies that appear to be well-suited for different scales (e.g., neighborhood, county, state) and different hazards (e.g., wildfire, flood), as well as explore how policies might change under different objectives (e.g., addressing inequities vs. minimizing overall costs). Example policy questions we intend to explore include:

Q1: What level of backup power and/or off-grid energy storage should be required at EV charging stations located along emergency corridors? Florida, which is affected annually by hurricanes, requires the installation of backup power at gas stations in order to ensure that vehicle refueling can occur during power outages and evacuations [45]. What locations and scenarios might warrant similar backup power approaches in California for EV charging infrastructure along key evacuation routes? What are some potential challenges and practical implications of such a requirement?

Q2: What are possible implications of policies and incentives for supporting or requiring backup power and infrastructure upgrades? Related to the question above, private entities and local governments, which currently operate most public EV charging stations and supporting electrical infrastructure, might lack financial resources and/or incentives to support the installation of backup power (and other infrastructure upgrades) to facilitate service provision during evacuations. Some utilities in California (e.g., PG&E) already have programs in place to mitigate impacts of outages by subsidizing the acquisition of generators and other backup power [46]. What aspects of these types of programs might be scalable to ensure sufficient backup power and infrastructure upgrades across the state? What policy mechanisms and/or economic incentives (e.g., grants, tax breaks) might facilitate private entities and local governments to upgrade their charging/power infrastructure and improve overall system resilience?

Q3: How might access to charging infrastructure during natural disasters be prioritized for ZEV-based emergency vehicles? Current road rules give priority access to critical vehicles such as police cars, ambulances, and fire trucks during emergency situations. As California transitions its transportation system toward clean vehicles, more emergency vehicles will be electrified. Therefore, priority access to charging networks for ZEV-based emergency vehicles might be particularly critical in the aftermath of a natural disaster, where the charging network might be compromised. Under these circumstances, what policies and practices might be considered for prioritizing access to charging networks?

Q4: What (in)equity considerations may emerge with respect access to charging infrastructure during emergency evacuations, and how can they be addressed? One of the main issues that limits EV adoption in California is the lack of charging infrastructure for people who live in apartments or homes without off-street parking [47]. These disadvantaged groups often need to park their cars on public streets with limited access to charging. This might become a significant shortcoming during evacuations. What actions, strategies, and policies might help reduce the possibility that specific communities are "stranded" and/or disproportionately impacted by ZEV evacuations? For example, under what conditions might the use of dedicated (mobile or fixed) charging stations be beneficial in certain locations? How might government entities strategically deploy public transit vehicles to facilitate evacuation efforts?

To answer these questions, we will build upon and adapt several interdisciplinary approaches, including benefit cost analysis [48], scenario analysis [49], interviews and surveys [50], and multi-criteria decision analysis [51]. Ultimately, the exploration of these policy questions will contribute to the development of resources (e.g., infographics, white papers, decision trees) that help government officials, community groups, and private entities decide on strategies for enhancing their ZEV evacuation readiness.

Task 5: Education, Community Outreach and Dissemination of Resources

Education and Workforce development: We will create education materials for disseminating best practices on ZEV evacuations. These materials will be grouped into three different modules: 1) analysis of vulnerabilities and capacity; 2) planning and preparedness; 3) emergency response. Each module will have a power system, charging infrastructure and transportation perspective to reflect the increasing multidisciplinary nature of ZEV evacuation plans. The research team will record short online modules, which will be made available on the project website for easy access by stakeholders. These education modules will also be integrated into undergraduate and graduate courses at different UC campus, such as Electric Vehicle Design (EE 188) and Sustainable Energy (ENV160; ES 260) at UC Merced; Energy Systems and Control (CE295) at UC Berkeley and Advanced Renewable Energy Sources, Storage, and Smart Grids (ECE180J) at UC Santa Cruz. They will equip our students with skills and knowledge to prepare them for the challenges posed by ZEV-based evacuations. Additionally, we also aim to transfer this knowledge to adult learners, who are already in the job market and aim to update their skills, via Berkeley ITS TechTransfer [12] and partnerships with the KCCD's South Valley ZEV Talent Pipeline initiative [52].

Community Outreach and Dissemination activities: To increase the impact and utilization of research findings among the community, we plan to conduct numerous activities to disseminate the knowledge created during the project execution (see Chapter 4 for a detailed list of dissemination activities).

1.2 Alignment with California Climate Priorities

Alignment with California Climate Adaptation Strategy (CCAS) [53]: One of the main priorities of CCAS is to strengthen protections for climate vulnerable communities (Prio. 1).

- Our ZEV readiness score will help "*identify the most climate vulnerable communities in California to direct and inform actions across sectors and regions that reduce risk and build resilience"* (Prio 1, Goal B, Actions 1)[1];
- The ZEV evacuation tools and resources developed in this project will be instrumental to "*assist emergency managers and planners in identifying, locating, and deploying resources to populations at greater risk from climate impacts*" (Prio. 1, Goal B, Action 5), and also to "*support actionable, community-driven, and equitable research partnerships to inform and accelerate climate adaptation action based on best available climate science.*" (Prio. 1, Goal B, Action 4).
- Our decision-aid resources will guide "*prioritization of investments that reduce climate risk to California's transportation system based on exposure and sensitivity analyses of climate change and natural disasters*." (Prio 2, Goal B, Action 6)[2]; and "*increase resilience of critical, climate vulnerable energy infrastructure"* (Prio2, Goal C, Action 2).

Alignment with California's Fifth Climate Change Assessment [54]: This assessment aims to support on-the-ground implementation of decision-making resources at local, regional, and state levels, with particular focus on the needs of communities most vulnerable to climate change impact. The resources and policy recommendations developed in our project are good examples of science-based tools that vulnerable communities can use to improve their ZEV preparedness during extreme weather events.

Alignment with Governor's Executive Order N-79-20 [1]: Our project is aligned with and supports Executive Order N-79-20 that establishes the goal of 100% new light-duty sales as ZEVs by 2035. This goal is critical to decrease tailpipe emissions from the transportation sector, which is the largest source of greenhouse gas emissions in our state [55]. However, for this to succeed, the state needs to be prepared to cope with "ripple effects" of this policy, particularly in evacuations. Our project creates resources that our communities can use to prepare for ZEV evacuations, ensuring that the shift toward clean transportation does not increase the vulnerability of front-line communities most impacted by climate change.

[1] *Climate Priority*: Strengthen Protection for Climate Vulnerable Communities; *Goal B*: Improve understanding of climate impacts on California's communities, including what drives vulnerability; *Actions*: 1, https://climateresilience.ca.gov/priorities/strengthen-protections/climate-impacts.html

[2] Climate Priority: Bolster Public Health and Safety to Protect Against Increasing Climate Risks, Goal B: Consider future climate impacts in governmental planning and investment decisions, Action 6

Alignment with Governor's Executive Order B-48-18 [56]: this executive order established the goal of having 250,000 chargers by 2025, while California Energy Commission [57] estimates that more than 1.2 million chargers (public and shared private) will be required by 2030. Our project is aligned with these priorities by recommending strategic deployment of EV chargers (mobile and fixed) that communities can adopt to reduce their vulnerabilities during ZEV evacuations.

1.3 Actionable Outcomes and Impacts

The project will create new knowledge and insights that deepen our understanding on how to prepare and respond to emergency evacuations using ZEVs. We will provide actionable outcomes (AO) that can be quickly transferred to communities in California. These actional outcomes include resources, decision-aid tools, policy recommendations and education materials that will be used to improve readiness of California communities to perform ZEV evacuations.

(AO1) Improve public policy recommendations. To translate our research findings into actionable recommendations for policymakers, we will develop a series of policy briefs and white papers (Task 4). The policy briefs will focus specifically on California legislators and will help lawmakers understand tradeoffs among various policies that can effectively support ZEV evacuations. Policies of interest will range from mandates for backup power on EV charging stations, economic incentives, equity aspects, among others. In addition, we will develop white papers that focus on the best approaches that communities can follow to analyze, prepare for, and respond to ZEV evacuations. These white papers will include examples from the case studies we conducted in Merced and Mariposa counties, making the information more relatable to other communities in California facing similar evacuation challenges. All policy briefs and white papers will be reviewed by the project's advisory board to ensure that different perspectives and concerns are represented in these recommendations (see Chapter 4 for details).

(AO2&AO3) New decision-aid tools and resources to improve preparedness for ZEV-based evacuations: Tasks 2 and 3 will develop a suite of resources that local authorities and emergency services can use to gain straightforward information about best practices, common barriers, and infrastructure investments needed to develop ZEV-ready evacuation plans. These resources will include factsheets, checklists, and flowcharts that can support communities in understanding the steps involved in ensuring effective ZEV evacuations, from planning to execution. Decision-aid tools will also be provided to help local authorities optimally place mobile EV chargers, and design evacuation routes that minimize overall evacuation times. This will allow them to identify strategies that align with their unique preferences and criteria, such as cost, ease of implementation, and geographic scale. By providing a range of data tools and resources, our project will empower local communities to effectively prepare for ZEV-based evacuations and reduce the risks associated with natural disasters.

(AO4) Workforce development and broadening participation in research: Task 5 will generate new education materials that will be incorporated into workforce development programs for our community partners. This will help individuals in California gain the necessary skills and knowledge to effectively plan and respond to emergency evacuations while considering the limitations of ZEVs. The project will also provide opportunities for graduate and undergraduate students across multiple UC campuses to receive training in emergency preparedness using ZEVs. Many of these students are from underrepresented groups. UC Merced, the lead institution in the project, is a designated Minority-Serving Institution (MSI), with over half of the undergraduate population identifying as Hispanic or Latino. Our project will provide an opportunity for these minorities to participate in multidisciplinary research, helping them become well-trained, well-equipped, and skilled technical workers in the field of ZEVs.

AO5: New scoring frameworks to identify populations that are vulnerable and unprepared for ZEV-based evacuations: Our project will create a standardized scoring system to evaluate communities' readiness for evacuation using ZEVs. This scoring system will facilitate information exchange and collaboration between different stakeholders. It provides a common set of metrics, which enables state and local governments, as well as emergency services, to identify vulnerable populations and direct resources to areas with the greatest need. By providing these resources, California communities will be better equipped to respond to natural disasters, reduce loss of life, and enhance overall resilience.

2. Timeframe, Milestones, and Evaluation Metrics:

			Year 1				Year 2			
#	Task	Lead/ Support	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Vulnerability analysis of ZEV-based evacuations	***Markolf***								
1a	Identify vulnerability and capacity indicators in power grid, charging and transportation networks	Keith, Parsa, Kurtz								
1b	Integration integrators into a final ZEV evacuation readiness score				**M1**					
2	Decision-support tools for improving preparedness of communities for ZEV-based evacuations	***Corzine***								
2a	Identify actions to mitigate infrastructure vulnerabilities	Markolf, Parsa, Kurtz								
2b	Development of resources and tools to guide infrastructure investments					**M2**				
2c	Cost-benefit analysis and prioritization of investments									
3	Design of ZEV-ready evacuation plans	***Moura***								
3a	Design and Implement co-optimization algorithms for mobile EV placement & ZEV-ready evacuation routes	deCastro, Xinfan, Markolf								
3b	Development of web application to facilitate visualization of evacuation plans among end-users									
3c	Pilot test and validation with case studies from Merced and Mariposa counties								**M4**	
4	Public policy to support effective ZEV-based evacuations	***Markolf***								
4a	First draft of public policy recommendations to support emergency evacuations that accommodate ZEVs	Kurtz, deCastro, Moura					**M3**			
4b	Refine recommendations based on surveys and feedback from government officials and other stakeholders									
5	Outreach and dissemination of knowledge	***deCastro***								
5a	Regular consultations with advisory committee	All								
5b	Creation of education materials for workforce development									**M5**
5c	Public workshops and seminars to share lessons learned									
6	Project Management	deCastro								

Figure 6. List of tasks, milestones (highlighted in red, M1, M2, M3, M4, M5) and responsibilities for the 2-year project.

Figure 6 details the project's five main technical tasks. The key milestones are:

- **M1 (**Year 1, Q3) the *ZEV Evacuation Readiness Score* methodology is developed, integrating vulnerability and capacity analysis from charging, power systems and transportation networks.
- **M2 (**Year 1, Q4) the decision-aid resources to support infrastructure investments that improve preparedness for ZEV evacuations are available.
- **M3 (**Year 2, Q1) first version of the public policy recommendations to support ZEV evacuations are published and shared with government authorities and other stakeholders.
- **M4** (Year 2, Q3) optimization-based tools and resources to develop ZEV evacuation plans are available and evaluated with real-world case studies.

- **M5 (**Year 2, Q4) education materials to support workforce development are available and integrated into continuing education programs.

Benchmarking: To assess the effectiveness of our resources and decision-aid tools, we will benchmark them on two scenarios. The first scenario represents a baseline case with no additional investment made in charging, power grid, and transportation infrastructures. The second scenario considers different investment levels in fixed/mobile charging, backup power generation, and other measures. For each scenario, we will analyze the impact of various natural hazards on the ZEV infrastructure, based on input from community partners. The goal is to quantify the cost of inaction (baseline scenario) and the advantages provided by proactive planning for ZEV evacuations.

Evaluation Metrics: To quantify the cost and benefit across the scenarios above we will adopt numerous evaluation metrics, described in Table 1. These metrics are divided into four main groups: i) preparedness for ZEV evacuation; ii) infrastructure capacity; iii) economic costs; iv) user-acceptance and behavior. The first three groups will be assessed using the numerical and decision-aid tools developed in Tasks 1-4; the assessment of user acceptance will be performed based on user satisfaction surveys [58].

Table 1. List of Evaluation metrics for the project

Type	Evaluation Metric
Preparedness for ZEV Evacuation	EM 1: Expected evacuation time for the community [min.]
	EM 2: ZEV Evacuation Readiness Score (ERS) of the community, with scale 0- very low to 5 – very high readiness.
Infrastructure Capacity	EM 3: Number of EV that can be charged/hour in and around the evacuation area
	EM 4: Number of vehicles/people per hour than can flow on evacuation route
Economic Cost	EM 4: Total investment in corrective measures to improve ZEV ERS, such as backup power, redundancy systems and components, among others [$]
	EM 5: Total investment to improve ZEV ERS, such as mobile EV chargers [$]
User Acceptance & Behavior	EM 6: Average satisfaction of stakeholders with recommended public policies to improve ZEV ERS (with numerical scale 0 – very low to 5 – very high satisfaction)
	EM 7: Willingness of end-users to follow evacuation plans generated by our decision-aid tools (with numerical scale 0 – very low to 5 – very high willingness)

3. Organizational Structure – Research Team, Collaboration, and Mutual Benefit:

Organizational structure of the team: The team is comprised of two main groups: the research team and the advisory committee. The research team is composed of seven researchers, supported by six graduate and three undergraduate students from four UC campuses (Merced, Santa Cruz, Berkeley, and Davis). To facilitate project management, these researchers are allocated into five taskforces dedicated to i) vulnerability analysis, ii) planning and preparedness, iii) emergency response, iv) public policy v) and outreach (see Figure 7). Each taskforce has a lead researcher, who has oversight over the respective actionable outcomes. The second group is the advisory committee of the project. This group of stakeholders offer data, guidance, and recommendations to the research team, bringing diverse perspectives to the project. In return, the committee members receive actional outcomes, such as resources, decision-aid tools, and education modules described in Sec. 1.3.

Complementary strengths of the team members: The project brings together a group of interdisciplinary experts with complementary knowledge and skills, all working together to address complex ZEV evacuation challenges. The team includes civil and environmental engineers from UC Merced and Berkeley who specialize in analyzing transportation networks, as well as electrical and mechanical engineers from UC Santa Cruz, Merced, and Davis who provide expertise in charging and power grid networks (see attached CVs for more details). The project will also leverage the resources provided by the advisory committee, which is comprised of numerous community and end-user partners.

- The *Office of Emergency Services at Mariposa and Merced Counties*, and the *Merced Fire Department* will provide real-world experience, data and knowledge in dealing with emergency evacuations.
- *CALSTART*, a non-profit organization, will facilitate stakeholder engagement and help share project results to their 200+ ZEV industry members, California state agencies, and policymakers [59].
- *KCCD* offers know-how and experience developing and implementing ZEV workforce education programs in Central Valley [52].
- *San Joaquin Valley Air Pollution Control District* provides insights and expertise related to public incentive programs for deployment of EV charging stations.
- *San Joaquin Valley EV Partnership*, a regional collaboration network with over 50 business partners and 40 public organizations, will facilitate the dissemination of project knowledge.
- Industry partners, such as *Motive Power Systems* (a ZEV manufacturer), *EVEN Recharge* (a developer of mobile EV chargers) and *Perimeter* (evacuation management software), will provide market insights and technological known-how to support ZEV evacuations.

Figure 7. Overview of the organization structure of the research team and advisory committee of the project.

Contributions of the team members: Figure 6 summarizes the contributions of each team member to each task.

- Sam Markolf, Sarah Kurz (UCM), Keith Corzine and Leila Parsa (UCSC) will contribute expertise to evaluate the readiness level of the charging, power grid and road networks to effectively support ZEV evacuations; and develop investment plans to improve resilience of these networks (Task 1, 2).

- Sam Markolf and Ricardo de Castro (UCM) will contribute with expertise on vulnerability analysis, public policy recommendations and lead the outreach and knowledge dissemination (Task 4, 5).
- Scott Moura (UCB) and Xinfan Lin (UCD) will contribute data collection and analysis on existing infrastructure, optimization tools for strategic placement of charging infrastructure and ZEV evacuation plans (Task 3).
- Ricardo de Castro (UCM) will coordinate the project, providing management and leadership (Task 6).

The research team have collaborated previously in research projects and professional organizations. For example, Markolf and deCastro are working together in a CARB research project[3]; deCastro, Corzine, Moura, Lin, Markolf, and Kurz jointly organized a technical conference dedicated to ZEVs in 2022 [60]. The research team will have frequent meetings, including monthly all-hand meetings to keep all project personnel working closely together and synchronized. We will use these meetings to share progress and roadblocks to keep the project on schedule and discuss next steps. The five taskforce leaders are responsible for the timely execution of the research work.

Overall plan for the team to harness these components for maximum impact: The community and end-users will be integrated into the advisory committee of the project. They will commit time to regularly meet with the research team and share data, insights, and knowledge (see next section and attached letters of commitment from each partner for details). This feedback will bring different perspectives to the project, helping the research team refine resources and decision-aid tools; it will also help identify strategies to effectively translate the project results to communities across California.

4. Community/End-User Engagement Plan

Engagement with Office of Emergency Services (OES) of Merced and Mariposa: The research team will collaborate with representatives from the Office of Emergency Services (OES's) of Merced and Mariposa counties to create real-world case studies that validate the effectiveness of our resources and decision-aid tools. The OES's have extensive knowledge and experience in preparing and coordinating local resources in response to natural disasters, making them valuable partners in building project case studies. Additionally, they are interested in gaining access to our decision-aid tools to better prepare for ZEV-based emergency evacuations. Therefore, our project will provide mutual benefits for both parties.

The case studies will prioritize communities at high risk of natural hazards. For example, we will focus on flood-induced evacuations in Merced due to the county's history of serious flooding events (54 over the last 30 years [20]). In cooperation with Merced OES's, we will build case studies based on the town of Planada and communities around Bear Creek, which were recently forced to evacuate due to massive flooding. With Mariposa OES's, we will build case studies focusing on emergency evacuations caused by wildfires, given the county's high risk of wildfire hazards [21]. During the project execution, we will apply the vulnerability analysis and decision-aid tool to these real-world case studies, informing these OES's on the most cost-effective and impactful strategies to improve their preparedness to ZEV evacuations. We anticipate that the knowledge and lessons learned from this pilot study can then be translated to other California communities that are currently transitioning to a ZEV-based transportation ecosystem and need to revise their evacuation preparedness to support clean vehicles.

Engagement with Kern Community College District (KCCD): We will collaborate with KCCD in workforce development activities. KCCD serves nearly 35,000 students through the Bakersfield College, Cerro Coso College and Porterville College. Currently, KCCD is leading multiple workforce development programs to support ZEV technology and infrastructure [52]. Our education materials developed in Task 5 will provide input for new modules dedicated to "*best practices for ZEV-based emergency evacuations*",

[3] CARB Project: *Assessing and Supporting Equitable Zero-Emissions Vehicle Ecosystems across all Modes and Communities*, 2023-2026

which can be integrated into the ongoing and future workforce development programs of KCCD. Additionally, we will collaborate with KCCD to assess the effectiveness of our education materials by collecting post-training feedback from students and instructors; this feedback can inform us on modifications/improvements needed to make the educational materials more effective.

Engagement with EV Charging Companies: Our project will also cooperate with EVEN Recharge, a California company that develops mobile EV chargers and backup power solutions. EVEN Recharge is interested in expanding their product line with mobile solutions that support ZEV-based evacuations. They will advise the research team on the techno-economic cost analysis of mobile chargers, leveraging their knowledge on manufacturing costs. In return, EVEN Recharge will gain a better understanding of the impact and sizing requirements of mobile charging for ZEV-based evacuation, which they can use to guide the development of future products.

Engagement with Advisory Committee: The advisory committee is initially composed of representatives from the office of emergency services (Mariposa, Merced), fire departments (Merced), non-profit organizations (CALSTART, San Joaquin Valley EV Partnership), community colleges (KCCD) and industry (Even Recharge, Motive, Perimeter). The project team will establish a Memorandum of Understanding (MOU) with all the committee members at the beginning of the project in order to formalize the rules of operation. The MOU will follow the best practices for community research collaboration, such as [61]. We plan to expand the advisory committee with additional community and end-user members, which the research team will recruit during the dissemination activities of the project.

Dissemination Activities: To increase the impact of research findings among the community, we plan to carry out numerous dissemination activities to share and spread the knowledge created during the project execution. We will share best practices and ZEV evacuation methods with policymakers, emergency managers, non-profit organizations, among other stakeholders; see Table 2 for details. This dissemination of knowledge activities plays a critical role in ensuring that research and knowledge are translated into action, leading to improvements in policy and the state-of-practice in ZEV evacuations.

Table 2. Overview of the project's dissemination activities and target audience.

#	Dissemination Channels	When	Audience
1	**Workshop** to disseminate best strategies for ZEV evacuations during the *Annual Conference of California Emergency Services Association* (CESA)	May 2024, May 2025	700 emergency managers in CA
2	**Seminar** with staff from state agencies (CARB, CEC, CalOES, CalTrans) to disseminate preliminary results and collect feedback	Sep. 2024	30+ staff from CA state agencies
3	Publish at least one article in the **Newsletter** of the *International Association of Emergency Managers* (IAEM)	Jan. 2025	6k stakeholders in emergency management
4	**Public Policy Workshop**, *CALSTART Policy Summit* [59]	March 2025	150+ policy makers
5	**Advanced Clean Transportation (ACT) Expo:** poster to raise awareness of ZEV evacuation among industry/general public	May 2025	8.5k ZEV stakeholders
6	**Final project workshop** at UC Merced to share lessons learned, tutorials on how to use decision-aid tools, interactive demonstrations of the resources	July 2025	80+ stakeholders
7	**Presentation of progress reports to the advisory board of the project**, composed of representatives from office of emergency services, non-profile organizations and private entities.	Every quarter	Stakeholders in emergency management
8	**Official project website**. Updated central source of information, including infographics, factsheets, among others resources.	Available by Oct 2023	General public
9	**Social networks**. LinkedIn for professionals. Twitter to advertise project's running activities and findings. Facebook for communication with general public. YouTube for videos.	Available by Dec. 2023	General public

10	**Media impressions:** at least one media impression (coverage) of the final project workshop	July 2025	General public
11	**Publications**: At least six open-access peer-reviewed articles and research papers for dissemination of scientific results	By July 2025	Scientific community

Leveraging Plan

To sustain and expand this project, we aim to pursue a combination of federal and state funding: The *University Transportation Center (UTC)* is a program under the US Department of Transportation (DOT) that provides funding to consortia of universities to "build more resilient and sustainable transportation systems to benefit and protect communities" [62], which is well aligned with the scope of this seed proposal. The four UC campuses involved in this proposal (UC Merced, UC Santa Cruz, UC Berkeley and UC Davis) will submit a proposal to form a UTC center of excellence dedicated to resilience, including ZEV-based evacuations, which can build upon the preliminary results of this seed grant.

The US DoT recently established a new *Charging and Fueling Infrastructure (CFI) Discretionary Grant Program* [63], which will provide $2.5 billion over five years to strategically deploy publicly accessible electric vehicle charging and alternative fueling infrastructure in urban and rural areas. The research team plans to collaborate with Mariposa County, Merced County, Merced City, and other local jurisdictions, in order to apply for these larger grants. Our goal is to prepare California communities to effectively deal with ZEV emergencies, leveraging the tools and knowledge created in this seed project.

The *Grid Resilience Utility and Industry Grants* (GRIP) [64] is a US Department of Energy (DOE) program that supports the modernization of the electric grid to reduce impacts due to extreme weather and natural disasters. It provides $500 million/year FY 22-26 to modernize electric transmission and distribution technology and to mitigate multiple hazards, including wildfires, floods, hurricanes, storms, and any other event that can cause a disruption to the power system. We anticipate that this program will help our group continue developing resources and tools that can help identify key investments in electric grid, which are crucial to prepare for ZEV evacuations. The *Advanced Research Projects Agency - Energy (ARPA-E)* has historically supported research projects that strengthen and build security of our national power grid electric vehicle eco-system. Presently, ARPA-E has current funding opportunities in these areas, e.g., GOPHURRS and ULTRAFAST. Several co-PIs (S. Moura, K. Corzine, L. Parsa) received awards from ARPA-E, and we anticipate that numerous future funding opportunities will be available in the next years from this program. Finally, the *Advanced Research Projects Agency – Infrastructure (ARPA-I)* will come online within the next year, and focus on resilience and zero emissions mobility, among other topics [65].

The National Science Foundation (NSF) supports follow up grants to gain further fundamental understanding related to disaster resilience. Last year, NSF opened an RFP for *Disaster Resilience Research Grants (DRRG)* [66]. We anticipate similar opportunities in the next years.

At state level funding, the California Energy Commission (CEC), as the lead state agency for infrastructure planning and deployment for zero emission vehicles, is in a favored position to leverage the results of this award. One of their main priorities, described in the CEC 2022 Action Plan [67], is to support strategies that can improve resilience of electric vehicle charging stations. CEC also has plans to release a solicitation later this year [68] that will support projects to increase resilience of critical community facilities against power outages and wildfires, which are crucial for ZEV evacuations. California Climate Investments is another program that can fund follow-up projects, e.g., *Clean Mobility Options* [69] that funds needs assessments and ZEV transportation projects.. Finally, the Governor's Office of Planning and Research is currently managing the *Adaptation Planning Grant Program (APGP)*, a $25M (FY 22-25) program that supporting climate adaptation and resilience through planning, research, capacity building, restoration, and sustainable infrastructure. In cooperation with our community partners, we will submit multiple grant proposals to the APGP, Clean Mobility and CEC solicitations, among other state opportunities, to expand and sustain our research program.

References:

[1] Executive Department, State of California, “Executive Order N-79-20.” [Online]. Available: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf. [Accessed: 19-Feb-2023].

[2] Listos California, “Building Disaster Resiliency: A Roadmap for Investment and Innovation in California.” [Online]. Available: https://www.listoscalifornia.org/wp-content/uploads/2020/08/Building-Disaster-Resiliency.pdf. [Accessed: 25-Mar-2025].

[3] Intergovernmental Panel on Climate Change, “Climate Change 2022: Impacts, Adaptation and Vulnerability.” [Online]. Available: https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/. [Accessed: 01-Apr-2023].

[4] M. Rodell and B. Li, “Changing intensity of hydroclimatic extreme events revealed by GRACE and GRACE-FO,” *Nature Water*, vol. 1, no. 3, pp. 241–248, Mar. 2023.

[5] S. D. Wong, J. C. Broader, and S. A. Shaheen, “Review of California Wildfire Evacuations from 2017 to 2019,” *University of California Institute of Transportation Studies*, Mar. 2020.

[6] US Department of Energy (DOE), “FOTW #1221, January 17, 2022: Model Year 2021 All-Electric Vehicles Had a Median Driving Range about 60% That of Gasoline Powered Vehicles.” [Online]. Available: https://www.energy.gov/eere/vehicles/articles/fotw-1221-january-17-2022-model-year-2021-all-electric-vehicles-had-median. [Accessed: 01-Apr-2023].

[7] Electrek, “The top 10 fastest-charging EVs currently available.” [Online]. Available: https://electrek.co/2022/07/08/fastest-charging-evs/. [Accessed: 01-Apr-2023].

[8] Drive Clean, “Electric Car Charging Overview.” [Online]. Available: https://driveclean.ca.gov/electric-car-charging. [Accessed: 01-Apr-2023].

[9] California Energy Comission, “Electric Vehicle Chargers in California.” [Online]. Available: https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/electric-vehicle. [Accessed: 25-Mar-2023].

[10] California Public Utilities Commission, “Utility Public Safety Power Shutoff Plans (De-Energization).” [Online]. Available: https://www.cpuc.ca.gov/psps/. [Accessed: 01-Apr-2023].

[11] Sonoma Clean Power, “PG&E Public Safety Power Shutoff Frequently Asked Questions.” [Online]. Available: https://sonomacleanpower.org/uploads/documents/PSPS-FAQs.pdf. [Accessed: 02-Apr-2023].

[12] “Berkeley TechTransfer.” [Online]. Available: https://www.techtransfer.berkeley.edu/. [Accessed: 05-Apr-2023].

[13] M. Ghorbanzadeh, M. Koloushani, E. E. Ozguven, A. Vanli, and R. Arghandeh, “City transportation network vulnerability to disasters: the case of Hurricane Hermine in Florida,” *Environ. Hazards*, vol. 21, no. 3, pp. 199–217, May 2022.

[14] M. A. P. Taylor, *Vulnerability Analysis for Transportation Networks*. Elsevier, 2017.

[15] G. Raman, G. Raman, and J. C.-H. Peng, “Resilience of urban public electric vehicle charging infrastructure to flooding,” *Nat. Commun.*, vol. 13, no. 1, p. 3213, Jun. 2022.

[16] M. Glombek, H. J. Lees, H. van den R., and R., “Vulnerability Of Charging Infrastructure, A Novel Approach For Improving Charging Station Deployment,” in *7th Transport Research Arena TRA 2018*, 2018.

[17] A. Abedi, L. Gaudard, and F. Romerio, “Review of major approaches to analyze vulnerability in power system,” *Reliab. Eng. Syst. Saf.*, vol. 183, pp. 153–172, Mar. 2019.

[18] I. B. Sperstad, G. H. Kjølle, and O. Gjerde, “A comprehensive framework for vulnerability analysis of extraordinary events in power systems,” *Reliab. Eng. Syst. Saf.*, vol. 196, p. 106788, Apr. 2020.

[19] "California Hazard Map Reports," *Listos California*. [Online]. Available: https://www.listoscalifornia.org/about/research/hazard-map-reports-english/. [Accessed: 01-Apr-2023].

[20] Merced County, "Merced County Multi-Jurisdictional Hazard Mitigation Plan," 2021. [Online]. Available: https://web2.co.merced.ca.us/pdfs/oes/MercedCounty-MJHMP-2021-2016.pdf. [Accessed: 01-Apr-2023].

[21] "Mariposa County Local Hazard Mitigation Plan," *http://www.mariposacounty.org/documentcenter/view/80852/public-draft-lhmp_jan-6-2020_compiled-*. [Online]. Available: http://www.mariposacounty.org/DocumentCenter/View/80852/Public-Draft-LHMP_Jan-6-2020_compiled-. [Accessed: 01-Apr-2023].

[22] B. Nijenhuis, M. E. T. Gerards, G. Hoogsteen, and J. L. Hurink, "An Outage Probability Model for Electric Vehicles in Low Voltage Grids," in *2021 IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe)*, 2021, pp. 1–5.

[23] S. A. Markolf, C. Hoehne, A. Fraser, M. V. Chester, and B. S. Underwood, "Transportation resilience to climate change and extreme weather events – Beyond risk and robustness," *Transp. Policy*, vol. 74, pp. 174–186, Feb. 2019.

[24] S. A. Markolf *et al.*, "Interdependent infrastructure as linked social, ecological, and technological systems (SETSs) to address lock-in and enhance resilience," *Earths Future*, vol. 6, no. 12, pp. 1638–1659, Dec. 2018.

[25] "Review on multi-criteria decision analysis aid in sustainable energy decision-making," *Renewable Sustainable Energy Rev.*, vol. 13, no. 9, pp. 2263–2278, Dec. 2009.

[26] P. H. Dos Santos, S. M. Neves, D. O. Sant'Anna, C. H. de Oliveira, and H. D. Carvalho, "The analytic hierarchy process supporting decision making for sustainable development: An overview of applications," *J. Clean. Prod.*, vol. 212, pp. 119–138, Mar. 2019.

[27] B. M. de Alcântara Dias *et al.*, "An Analytic Hierarchy Process for Selecting Battery Equalization Methods," *Energies*, vol. 15, no. 7, p. 2439, Mar. 2022.

[28] Q. Huanhuan, D. Zhanfeng, Z. Guoliang, L. Zhengang, Z. Zhe, and H. Zhao, "Protection and Fault Recovery Strategy of AC and DC System of Flexible Substation," in *2019 IEEE 8th International Conference on Advanced Power System Automation and Protection (APAP)*, 2019, pp. 182–185.

[29] California Public Utilities Commission, "CPUC Undergrounding Programs Description." [Online]. Available: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/electric-reliability/undergrounding-program-description. [Accessed: 01-Apr-2023].

[30] "Flooding and Underground Cables: Myth or Reality?," *T&D World*, 23-Oct-2018. [Online]. Available: https://www.tdworld.com/intelligent-undergrounding/article/20971838/flooding-and-underground-cables-myth-or-reality. [Accessed: 01-Apr-2023].

[31] S. Zhu, K. Ota, and M. Dong, "More Power to Save Lives: Distributed Power Scheduling in Smart Microgrid for Disaster Management," in *2021 IEEE Global Communications Conference (GLOBECOM)*, 2021, pp. 1–6.

[32] S. Afshar, P. Macedo, F. Mohamed, and V. Disfani, "Mobile charging stations for electric vehicles — A review," *Renewable Sustainable Energy Rev.*, vol. 152, p. 111654, Dec. 2021.

[33] "GenCell launches grid-independent hydrogen EV charging solution EVOX," *Green Car Congress*. [Online]. Available: https://www.greencarcongress.com/2022/09/20220916-evox.html. [Accessed: 01-Apr-2023].

[34] E. Triantaphyllou, "Multi-Criteria Decision Making Methods," in *Multi-criteria Decision Making Methods: A Comparative Study*, E. Triantaphyllou, Ed. Boston, MA: Springer US, 2000, pp. 5–21.

[35] S. A. Markolf, M. V. Chester, A. M. Helmrich, and K. Shannon, "Re-imagining design storm criteria for the challenges of the 21st century," *Cities*, vol. 109, p. 102981, Feb. 2021.
[36] M. Buhl and S. Markolf, "A review of emerging strategies for incorporating climate change considerations into infrastructure planning, design, and decision making," *Sustainable and Resilient Infrastructure*, vol. 8, no. sup1, pp. 157–169, Jan. 2023.
[37] S. A. Markolf, A. Helmrich, Y. Kim, R. Hoff, and M. Chester, "Balancing efficiency and resilience objectives in pursuit of sustainable infrastructure transformations," *Current Opinion in Environmental Sustainability*, vol. 56, p. 101181, Jun. 2022.
[38] A. Helmrich *et al.*, "Centralization and decentralization for resilient infrastructure and complexity," *Environ. Res.: Infrastruct. Sustain.*, vol. 1, no. 2, p. 021001, Jul. 2021.
[39] Y. Wang, A. O. Rousis, and G. Strbac, "On microgrids and resilience: A comprehensive review on modeling and operational strategies," *Renewable Sustainable Energy Rev.*, vol. 134, p. 110313, Dec. 2020.
[40] Y. Ju, T. Zeng, Z. Allybokus, and S. Moura, "Robo-Chargers: Optimal Operation and Planning of a Robotic Charging System to Alleviate Overstay," *arXiv [eess.SY]*, 07-Dec-2022.
[41] P. Keyantuo, R. Wang, T. Zeng, A. Vishwanath, H. Borhan, S. J. Moura, "Distributionally Robust and Data-Driven Solutions to Commercial Vehicle Routing Problems," in *IFAC World Congress 2023*.
[42] T. Zeng, S. J. Moura, Z. Zhe, "Joint Mobility and Vehicle-to-Grid Coordination in Rebalancing Shared Mobility-on-Demand Systems," in *IFAC World Congress 2023*.
[43] "Perimeter App." [Online]. Available: https://app.perimeterplatform.com/. [Accessed: 05-Apr-2023].
[44] J. Ulitskaya, "What's Bidirectional Charging and Which EVs Offer It?," *Cars.com*, 28-Sep-2022. [Online]. Available: https://www.cars.com/articles/whats-bidirectional-charging-and-which-evs-offer-it-457608/. [Accessed: 01-Apr-2023].
[45] "Electric vehicles and natural disaster policy implications," *Energy Policy*, vol. 112, pp. 437–448, Jan. 2018.
[46] PG&E, "Community Wildfire Safety Program." [Online]. Available: https://www.pge.com/pge_global/common/pdfs/safety/emergency-preparedness/natural-disaster/wildfires/Portable-Battery-Program-Fact-Sheet.pdf.
[47] C.-W. Hsu and K. Fingerman, "Public electric vehicle charger access disparities across race and income in California," *Transp. Policy*, vol. 100, pp. 59–67, Jan. 2021.
[48] N. A. Leary, "A Framework for Benefit-Cost Analysis of Adaptation to Climate Change and Climate Variability," *Mitigation and Adaptation Strategies for Global Change*, vol. 4, no. 3, pp. 307–318, Sep. 1999.
[49] M. Berbés-Blázquez *et al.*, "Assessing Future Resilience, Equity, and Sustainability in Scenario Planning," in *Resilient Urban Futures*, Z. A. Hamstead, D. M. Iwaniec, T. McPhearson, M. Berbés-Blázquez, E. M. Cook, and T. A. Muñoz-Erickson, Eds. Cham: Springer International Publishing, 2021, pp. 113–127.
[50] Y. Kim, N. B. Grimm, M. V. Chester, and C. L. Redman, "Capturing practitioner perspectives on infrastructure resilience using Q-methodology," *Environ. Res.: Infrastruct. Sustain.*, vol. 1, no. 2, p. 025002, Jul. 2021.
[51] J. Ma, J. D. Harstvedt, R. Jaradat, and B. Smith, "Sustainability driven multi-criteria project portfolio selection under uncertain decision-making environment," *Comput. Ind. Eng.*, vol. 140, p. 106236, Feb. 2020.
[52] California Energy Commission, "South Valley ZEV Talent Pipeline Project." [Online]. Available: https://www.energy.ca.gov/filebrowser/download/4071. [Accessed: 28-Mar-2023].
[53] State of California, "California Climate Adaptation Strategy." [Online]. Available: https://www.climateresilience.ca.gov/. [Accessed: 05-Apr-2023].

[54] "California's Fifth Climate Change Assessment:" [Online]. Available: https://opr.ca.gov/climate/icarp/climate-assessment/. [Accessed: 05-Apr-2023].

[55] California Air Resources Board (CARB), "California Greenhouse Gas 2000-2020 Emissions Trends and Indicators Report." [Online]. Available: https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/2000-2020_ghg_inventory_trends.pdf. [Accessed: 19-Feb-2023].

[56] Executive Department, State of California, "Executive Order B-48-18." [Online]. Available: https://www.ca.gov/archive/gov39/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/index.html. [Accessed: 19-Feb-2023].

[57] California Energy Commission, "Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment Analyzing Charging Needs to Support Zero-Emission Vehicles in 2030," 2021.

[58] J. de Oña and R. de Oña, "Quality of Service in Public Transport Based on Customer Satisfaction Surveys: A Review and Assessment of Methodological Approaches," *Transportation Science*, vol. 49, no. 3, pp. 605–622, Aug. 2015.

[59] "CALSTART Policy Summit," *CALSTART*, 04-Jan-2023. [Online]. Available: https://calstart.org/policy-summit/. [Accessed: 01-Apr-2023].

[60] "2022 IEEE Vehicle Power and Propulsion," *VPPC2022*. [Online]. Available: https://events.vtsociety.org/vppc2022/. [Accessed: 01-Apr-2023].

[61] Palermo A, McGranaghan R and Travers, R., "Developing and Sustaining Community-Based Participatory Research Partnerships: Skills-Building Curriculum,." [Online]. Available: http://www.cbprcurriculum.info/. [Accessed: 01-Apr-2023].

[62] U.S. Department of Transportation (DoT), "U.S. DOT Strategic Plan FY 2022-2026." [Online]. Available: https://www.transportation.gov/sites/dot.gov/files/2022-04/US_DOT_FY2022-26_Strategic_Plan.pdf. [Accessed: 19-Feb-2023].

[63] "Charging and Fueling Infrastructure Discretionary Grant Program." [Online]. Available: https://www.fhwa.dot.gov/environment/cfi/. [Accessed: 04-Apr-2023].

[64] Department of Energy, "Grid Resilience Utility and Industry Grants." [Online]. Available: https://www.energy.gov/gdo/grid-resilience-utility-and-industry-grants. [Accessed: 04-Apr-2023].

[65] "The Potential Role of ARPA-I in Accelerating the Net-Zero Game Changers Initiative," *The White House*, 07-Dec-2022. [Online]. Available: https://www.whitehouse.gov/ostp/news-updates/2022/12/07/the-potential-role-of-arpa-i-in-accelerating-the-net-zero-game-changers-initiative/. [Accessed: 05-Apr-2023].

[66] NSF - National Science Foundation, "Disaster Resilience Research Grants (DRRG)." [Online]. Available: https://beta.nsf.gov/funding/opportunities/disaster-resilience-research-grants-drrg. [Accessed: 04-Apr-2023].

[67] California Energy Commission, "CEC 2022 Action Plan." [Online]. Available: https://business.ca.gov/wp-content/uploads/2022/04/CEC-2022-Action-Plan.pdf.

[68] California Energy Commission, "Optimizing Long-Duration Energy Storage to Improve Grid Resiliency and Reliability in Disadvantaged and Low-Income Communities and Native American Tribes." [Online]. Available: https://www.energy.gov/solicitations/2022-07/optimizing-long-duration-energy-storage-improve-grid-resiliency-and. [Accessed: 04-Apr-2023].

[69] "Clean Mobility Options," 23-Sep-2021. [Online]. Available: https://cleanmobilityoptions.org/. [Accessed: 04-Apr-2023].