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Edited by José C. Matos, Paulo B. Lourenço, Michael Beer, Daniel Oliveira, Edoardo Patelli, Hélder S. Sousa, Rui A. Silva and Monica Santamaria

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Preliminary Indicators for Social and Human Resilience: An Exploratory Approach for Infrastructure Safety

Emilia Araújo

Department of Sociology, University of Minho, Portugal. era@ics.uminho.pt

Monica Santamaria-Ariza

Department of Civil Engineering, University of Minho, ISISE, ARISE, Portugal. msantamaria@civil.uminho.pt

Hélder S. Sousa

Department of Civil Engineering, University of Minho, ISISE, ARISE, Portugal. sousa.hms@gmail.com

José C. Matos

Department of Civil Engineering, University of Minho, ISISE, ARISE, Portugal. jmatos@civil.uminho.pt

Extreme events derived from climate change, as floods, heat waves, power outages, and cascading failures are placing critical infrastructures under increasing pressures. This paper starts with the assumption that critical infrastructures are socio-technical systems: their performance depends not only on physical assets, but also on the social vulnerability, adaptive capacity, and resilience of the populations and territories they serve. Developed within the framework of the MED-IREN project, this article proposes a participatory methodological framework to integrate social vulnerability and human resilience into the climate preparedness of critical infrastructures in Mediterranean regions. Participation is understood as an integral component of policymaking and a key condition for governance under pressure. In addition, this position paper highlights the importance of decision-support data centres dedicated to resilience and prevention policies, as well as research centres focused on future studies through cross-disciplinary methodological approaches, including ethnography, qualitative research, and scenario-building exercises. The main contribution is to frame infrastructure resilience as a socio-technical and participatory process oriented towards social justice, preparedness, and long-term adaptation to climate uncertainty.

Keywords: social vulnerability, social resilience, human resilience, critical infrastructure, climate preparedness, Mediterranean regions, participatory methodological framework, decision support, Nature-based Solutions

1. Introduction

This paper is addressed primarily to policymakers. Its purpose is to highlight the main indicators of social vulnerability and social resilience that should be considered in all decision-making processes concerning preparedness for and anticipation of extreme events. It also aims to emphasize the need for decision-support data centres in these areas and for the inclusion of public participation as a daily and interdisciplinary working methodology.

Considered a fundamental dimension in the definition of a wide range of social support measures, social vulnerability and social resilience are now widely recognised as central components of any prevention and preparedness plan for extreme events. In broad terms, they refer to the capacity of individuals and communities to respond to disasters, recover from their impacts, and anticipate future consequences. To understand the importance of incorporating social indicators, it is necessary to recognise that any technical infrastructure is, in fact, a socio-technical system. As such, it involves both technical components related to design, predictability, technological assessment, and statistical estimation, and dimensions associated with the characteristics of the people involved and the communities in which the infrastructure is embedded (Rinaldi et al., 2001; Bruneau et al., 2003).

In almost every example that could be given—including the recent floods that occurred in Portugal in 2026—people with more vulnerable characteristics, such as older adults, people with disabilities or chronic illnesses, those living alone, or families with lower incomes living in areas with limited access to services, from food provision to transportation, tend to be disproportionately affected. These populations often experience higher mortality rates and more severe consequences. In addition to socioeconomic and health-related vulnerabilities, there is also informational vulnerability, which may be linked to both access to information technologies, including mobile phones and the internet, and to the ability to understand and interpret warning messages.

Public policy must therefore devote greater attention to understanding the characteristics of populations and assessing their living conditions in order to prevent further vulnerability in critical situations, whether foreseeable or not. Decision-making cannot rely solely on restrictions or regulations concerning certain activities, such as housing construction, building materials, or design choices. It must also include a concrete assessment of territories and populations, as well as anticipation of the structural vulnerabilities that may characterise particular places—for example, the construction of housing near cliffs or on steep slopes, or the selection of building materials and housing designs that may not be suited to expected climatic conditions.

The same applies to resilience, which requires preparing and empowering populations. Decision-makers also need continuous data centres capable of monitoring local conditions, available resources, and coordination mechanisms. These systems should provide information on where populations are located, what they are able to do, and how they can prepare for different types of events, including floods, heatwaves, or emergency evacuations resulting from unexpected incidents in densely populated areas.

This position paper discusses the concepts and theoretical perspectives related to social and human factors affecting resilience and proposes a participatory methodological framework for addressing these issues in the context of critical infrastructure preparedness and climate adaptation.

2. Theory and method

2.1. Social vulnerability

Social vulnerability defines situations of dependency and fragility that may involve social, economic, demographic, institutional, and territorial variables, making certain people and/or communities more exposed to, or less able to defend themselves against, respond to, and recover from the effects of extreme events. Strongly linked to social and economic capital, vulnerability refers to the amount and robustness of resources, mobility options, disability and health conditions, housing security, and support networks that people possess and can mobilize before a crisis (Cutter et al., 2003). As Birkmann (2006) notes, measuring vulnerability is useful for prevention, but it requires caution in order to avoid reducing complex social realities to decontextualized numbers.

The concept mainly shows that technical actors and infrastructure systems need to address these levels of vulnerability and consider them as a highly relevant matter for anticipating and responding to disasters. Thus, a power outage, a flood, or a communication failure does not have the same meaning for all social groups. Research on critical infrastructure has increasingly recognized that resilience must be assessed across multiple dimensions. Osei-Kyei et al. (2023) identify criteria such as safety, risk analysis, recovery, connectivity, organizational resilience, community resilience, and social responsibility. This approach supports the need for indicators that go beyond the physical assessment of systems and allow for an understanding of differentiated social effects.

Garschagen and Sandholz (2018) argue that governance of critical infrastructure failures should integrate social vulnerability and the definition of minimum essential service provisions. Mendes et al. (2020) demonstrate the importance of local assessments of social vulnerability for planning. Copeland et al. (2020) warn that social resilience indicators imply normative choices about what is understood by community, adaptation, recovery, and transformation.

Geekiyanage et al. (2020) emphasize that vulnerable communities are often marginalized in decision-making processes, which makes it necessary to create specific mechanisms for inclusion and representation. Therefore, the construction of indicators must be transparent and, whenever possible, validated with local actors. The indicators do not replace political and technical judgment, but organize the information necessary for fairer and more informed decisions (Ciccotti et al., 2020). Also, Coleman et al. (2024) argue that equity should be integrated into research and practice on infrastructure resilience.

2.2. Social and human resilience

Social resilience is understood as the capacity of individuals, households, communities, and institutions to anticipate risks, absorb impacts, adapt practices, and recover living conditions after a disruption. Human resilience, in this article, brings this definition closer to the concrete capabilities of people: caring, moving around, understanding warnings, asking for help, maintaining health, protecting income, rebuilding housing, and participating in decisions that affect their territory. Norris et al. (2008) define community resilience as a set of adaptive capabilities, including economic resources, communication, collective skills, and social capital. Keck and Sakdapolrak (2013) show that social resilience includes capacities for resistance, adaptation, and transformation. Saja et al. (2021) also state that, in disaster management, social resilience is related to literacy, depends on personal features, but also on real living conditions and resources.

The functional continuity of a bridge, power grid, water system, or transport corridor must be evaluated in relation to the people who depend on it, the institutions that manage it, and the data that guide decision-making. Recent literature on critical infrastructure insists on the need for measurable and operational indicators (De Marco et al., 2025; Kammouh and Chahrour, 2025), but these indicators are only usable if they incorporate social, institutional, and participatory dimensions. International experience with early warning systems shows, for example, that communication is only effective when it reaches populations, is understood, is reliable, and can be transformed into action (UNDRR and WMO, 2024). Table 1 summarizes the twelve social and human dimensions that should be considered when assessing resilience and supporting infrastructure decision-making.

Table 1. Social and human dimensions.

Dimension	Use in decision-making
Demographic sensitivity	Identify the groups most vulnerable to the impact.
Health and disability	Planning care, evacuation, and home support.
Socioeconomic conditions	Define priorities, support, and compensation.
Mobility and accessibility	Organize accessible transportation, routes, and evacuation.
Housing	Provide guidance on shelter, relocation, and rehabilitation.
Energy	Plan for backup and continuity of essential services.
Water and sanitation	Plan distribution, drainage, and sanitary surveillance.
Communication	Ensure that warnings are accessible, understood, and reliable.
Social capital	Activate neighbourhoods, associations, and local mediators.
Institutional capacity	Clarify roles, protocols, and cooperation.
Social justice	Avoid unfair or exclusionary solutions.
Recovery capacity	Support material, emotional, and social recovery.

Source: authors' own elaboration

Demographic sensitivity, health, and disability allow for the identification of populations requiring differentiated support. Children, the elderly, people living alone, people with chronic illnesses, reduced mobility, or dependence on electrical equipment may face increased risks during heat waves, floods, power outages, or transport disruptions. Apart from the need to reduce vulnerability levels among certain groups, it is important that policymakers have updated and integrated information for each case. As already stated, this information includes socioeconomic conditions, housing, energy, water, and sanitation, and it helps to understand how intervention plans need to take into account the diversity of situations. Households with low incomes, unstable employment, lack of savings, precarious housing, energy poverty, or reduced access to insurance may be more severely affected and recover more slowly. Specific groups, such as women, migrants, or ethnic minorities, may also face greater difficulties.

Thus, vulnerability and resilience are strongly associated. Infrastructures are complex systems that rely not only on technical robustness, but also on people's ability to react, protect their lives, and access support. At the same time, vulnerability analysis allows us to infer the amount and type of services required from public policies. Conditions for mobility and displacement, social networks, and institutional empathy are important variables that help explain people's actions. For instance, credibility and trust are fundamental to encouraging people to adopt certain behaviours. Issues of justice and fairness are particularly relevant when rescue plans include evacuations or require people to adopt specific behaviours, because if these measures are not perceived as fair, or if they do not facilitate access to better resources and safer conditions — for example, by avoiding overcrowded spaces — they are less likely to be followed.

The role of associations, recreational groups, and village representatives is also of fundamental importance in mapping situations of exclusion, isolation, or higher risk. Additionally, they are structurally relevant for avoiding the unequal effects of policies, including the risk of marginalizing certain groups, for instance when policies disregard the quantitative and symbolic value of land. The emergence of inequalities at this stage is a phenomenon that experts and decision-makers need to understand.

Therefore, the framework must always ask who benefits, who bears the risk, who participates, and who recovers first. For decision-makers and infrastructure managers, these indicators can support the identification of vulnerable areas, the design of evacuation and shelter plans, the prioritization of investments, the continuity of essential services, risk communication, and post-event recovery. However, indicators can also oversimplify complex realities, ignore informal practices, or reproduce institutional biases. For this reason, they should be periodically reviewed and validated with local actors, especially vulnerable groups. The framework should be linked to decision-support centres, territorial observatories, or continuous data systems that combine statistical, geospatial, institutional, and participatory information.

3. Participation as a measure

Integrating social and human indicators into infrastructure safety requires more than just data collection. It demands participatory validation. Indicators can identify relevant dimensions of vulnerability, but they do not fully explain how risks are experienced, interpreted, and managed by local populations. The same distance to a hospital, for example, can have different meanings in a rural area with limited transport or in an urban area with several alternatives.

When communities are involved in identifying risks, validating indicators, and discussing solutions, infrastructure planning becomes more transparent and socially grounded. However, participation should not be reduced to symbolic consultation. It should be designed as a continuous process, with clear objectives, ethical safeguards, and visible influence on decision-making.

3.1. Stakeholder mapping

Stakeholder mapping is a very important phase for enhancing participation. It may normally involve public authorities, operators, civil protection, health services, schools, social services, non-governmental organizations, local associations, experts, residents, property owners, vulnerable groups, and informal leaders.

The goal is to understand roles, responsibilities, interests, resources, conflicts, dependencies, and trust relationships. In a crisis situation, unclear responsibilities or weak coordination can delay the response and increase damage. Therefore, the mapping should clarify who has authority, who possesses technical knowledge, who has local knowledge, who is recognized by the community, and who tends to be left out of formal processes. The principal functions of stakeholder mapping within the proposed participatory framework are summarized in Table 2.

Table 2. Functions of actor mapping in the methodological framework.

Function	Contribution
Identification	Selects actors to analyze vulnerability and resilience.
Validation	Confirms whether the indicators correspond to the local reality.
Coordination	Clarifies responsibilities, resources, and channels of cooperation.
Prioritization	Includes decision-makers and groups with less visibility.
Learning	Reassesses the situation when risks and relationships change.

Source: authors' own elaboration

3.2. Living Laboratories for anticipation measures and policies

Living laboratories or living labs are socio-technical arenas for co-creation. In the context of this article, they serve to test the framework in real-world situations, bringing together researchers, engineers, public authorities, operators, citizens, and local organizations. Their usefulness lies in shifting participation from a late stage to a process of co-definition, experimentation, and evaluation.

The logic of living labs is similar to the quadruple helix innovation model, which connects academia, industry, government, and civil society. Technicians and operators bring engineering knowledge; authorities bring institutional capacity; communities bring situated knowledge; and local organizations help reach less visible groups.

Living labs can support the validation of indicators, the discussion of Nature-based Solutions, scenario building, and the evaluation of social impacts. However, they must avoid tokenism, participant fatigue, and the reproduction of inequalities. To achieve this, they need careful facilitation, active inclusion of vulnerable groups, transparency about what can be decided, and feedback on the results to the participants. Table 3 presents the proposed phases of a living laboratory process and their respective contributions to participatory resilience planning.

Table 3. Possible phases of a living laboratory

Phase	Contribution
Co-initiation	Define the public problem and initial stakeholder map.
Co-definition	Establishes shared objectives and criteria.
Collaborative design	Discusses socio-technical alternatives and requirements.
Experimentation	Test solutions and record barriers and effects.
Co-evaluation	Evaluate benefits, drawbacks, and impacts.
Replication	Defines continuity, adaptation, and learning.

Source: authors' own elaboration

3.3. Decision-support data centres for future-oriented research

The article advocates for the creation or strengthening of decision-support centres dedicated to climate risk, infrastructure resilience, and social vulnerability. These centres could combine data on infrastructure, climate, hazards, social vulnerability, institutional capacity, communication, and recovery. The goal would not only be to produce maps, but to transform data into actionable knowledge for decision-makers, emergency planners, operators, and communities.

Their function is to support anticipation, preparedness, and continuous learning. However, data on vulnerable populations should not be used to stigmatize territories or justify exclusionary policies.

4. Discussion

The main implication of this article is that climate preparedness for critical infrastructure cannot be reduced to physical reinforcement, asset protection, or probabilistic hazard modeling. These elements are necessary, but not sufficient. Infrastructure may withstand the event better and still fail socially if it does not protect the populations that depend most on it or if the recovery reproduces previous inequalities. Safety is also the system's capacity to sustain human life, social organization, and territorial continuity under disruptive conditions (Linkov et al., 2013; De Marco et al., 2025). From a governance perspective, the framework demands integrated decision-making. A power outage can affect health, water, communication, transport, and home security. A flood may require coordination between municipalities, civil protection, police, social services, operators, and local associations. Without coordination, accurate knowledge, and stakeholder involvement, the most vulnerable populations tend to receive delayed or insufficient support.

5. Conclusion

This article argues that preparing critical infrastructure for climate risks requires integrating social vulnerability and human resilience into security, risk governance, and decision support. Critical infrastructure is a socio-technical arrangement embedded in territories, institutions, and communities. Its resilience depends not only on physical robustness, but also on the capacities and vulnerabilities of the populations it serves.

Within the framework of the MED-IREN project, this article proposes a participatory methodological framework for Mediterranean regions. This framework is understood as a decision support structure that combines concepts, indicators, and validation methods. It organizes social and human indicators into twelve dimensions and shows how these can support prevention, preparedness, response, recovery, and adaptation. The main contribution is to reframe infrastructure resilience as a socio-technical, participatory process oriented towards social justice. Future research should discuss this framework in specific territorial contexts, combining mixed indicators, geospatial mapping, qualitative participatory scenarios, institutional protocols, and evaluation of the social effects of Nature-based Solutions.

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