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A Holistic Asset-Level Modelling Framework for a Comprehensive Multi-Hazard Impact Assessment: Insights from the ICARIA Project

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The risk/impact assessment of climate-related extreme events has been historically addressed through single-hazard approaches that so far limited the development of a comprehensive, harmonized and integrated multi-hazard modelling framework capable of holistically understanding the weight of climate impacts on complex socio-eco-technological systems, as well as the definition of possible climate-resilient development pathways (IPCC, 2022). The expected increase in frequency and magnitude of meteorological hazards aggravated by climate change often manifests itself through the occurrence of complex interactions, characterised by compound events (e.g., floods and landslides, triggered by heavy rainfalls) and cascading effects (e.g., forest fires fuelled by persistent drought, triggered by heat wave conditions).

Depending on how the combination of these events occurs over time and space, the impacts resulting from multi-hazard conditions might be greater than the sum of the effects of individual hazards, and the nature of the damage will vary depending on both the complexity and interdependencies between hazards and/or impacts involved. Understanding the implications of compound events (whether coincident or consecutive) on specific categories of risk receptors – and of cascading effects arising from the propagation of impacts across assets and services – is the starting point to develop an asset-level modelling framework that effectively supports and orients decision-making processes towards the identification of strategies and measures to improve resilience.

In this perspective, a paradigm shift towards an effective multi-hazard impact modelling approach requires that 1) the possible interactions between hazards, and their dependence on global warming and climate change trends are taken into account, 2) the multi-sectoral consequences of complex impact scenarios leading to cascading effects are identified, and 3) the effect of possible

organizational, spatial, functional and physical resilience measures targeting multiple hazards are evaluated.

This contribution presents the holistic multi-hazard impact modelling framework developed within the EU-funded Horizon Europe ICARIA Project (Improving ClimAte Resilience of crItical Assets, www.icaria-project.eu, GA: 101093806). The framework aims at ensuring consistency in the analysis across different hazard categories (heat waves, forest fires, droughts, floods, storm surges, and wind gusts, including compound events), a harmonized evaluation of exposure and vulnerability of critical assets (buildings, open spaces and infrastructures) and services (water, transport, energy, waste, natural areas, and tourism sectors) potentially at risk, and the potential tangible direct and indirect impacts of complex multi-hazard scenarios, including cascading effects across interconnected service networks and systems. The modelling framework is also designed to quantify the benefits of resilience strategies and measures and to define suitable, sustainable and cost-effective solutions for climate resilience.

The methodological approach is grounded on interconnected “elementary bricks”, namely Hazard, (H) Exposure (E), Vulnerability (V), Dynamic Vulnerability (DV), and Damage (D), framed with respect to time and space interdependencies and interacting with local Coping Capacity (CC), Adaptive Capacity (AC) and Transformative Capacity (TC) as main resilience components. The contribution introduces relevant taxonomies, replicable modelling workflows, and quantifiable impacts and resilience metrics applicable in different geographical contexts, proposing a service-oriented implementation approach aimed at maximising the exploitation of existing models and data while introducing specific methods to address uncertainties and data/knowledge gaps.