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Resilience investments under climate change: a regional case study in Southeast Australia

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Many regions in Australia have experienced substantial damage to their natural, social, and environmental infrastructure from natural hazards. The scale and impact of these events have increased in recent decades due to the growing exposure and vulnerability of larger populations, economic activities, and infrastructure (both built and natural), as well as the intensification of natural hazards induced by climate change. Despite the increasing challenges, there is still limited investment in building resilience. Moreover, many local governments throughout Australia lack the necessary technical capabilities, knowledge, and funding to ensure the reliable ongoing delivery of essential services to communities, much less to identify, assess, and implement resilience interventions. The implementation becomes more challenging in the case of Nature-based Solutions for disaster resilience and climate adaptation where there are significant gaps in understanding and evidence of their effectiveness in the short and long term. This study proposes a discursive, place-based, and cross-scale approach to overcoming these challenges and enabling councils to develop resilient investment cases (RICs) as part of regional planning processes involving local governments, research institutions, and private sector stakeholders. The approach involves: collectively identifying values and vulnerabilities in a hazard-prone region in south-east Australia; prioritizing focal infrastructure asset types for investigation, in this case transport but relevant to all forms of critical infrastructure including nature; identifying suitable interventions for resilience planning under scenarios of change; and formulating RICs by assessing the effectiveness, costs, and benefits of bundles of resilience interventions under scenarios of change. We present the approach as applied in the Bega Valley Local Government Area which is highly exposed and vulnerable to impacts from natural hazards. Insights and lessons from the case

study are applicable to a range of critical infrastructure types, including nature-based solutions (green and blue infrastructure), as well as other regions in Australia and abroad that require resilient investment planning.

KEYWORDS

hazards, vulnerability, services, value creation, communities, Australia

1 Introduction

It is becoming increasingly clear that mitigating the physical risks of climate change and extreme weather events is an urgent priority, especially for vulnerable regions and communities. Climate-driven exacerbations of hazards have heightened the exposure of natural, social, and infrastructural assets. Meanwhile, changing demographics, population growth, and decisions regarding the location and design of settlements have intensified vulnerabilities and increased the value of assets at risk of disruption. The speed, scope, and scale at which people, places, and values are being impacted by intensifying natural hazards are redefining the need for "*resilience*"[1] planning and investment in regions (Alexander, 2013; Aldunce et al., 2014; Walker, 2020).

It has become difficult, however, for individual agencies, jurisdictions, or sectors to effectively diagnose and manage the complex and interconnected causes of climate and disaster risks (Buchtmann et al., 2023). These difficulties stem from numerous institutional, procedural, and methodological barriers that limit the ability of prevailing risk, economic, and financial assessment and management approaches to consider systemic climate risks and resilience. Some of these key limitations include:

1. Widespread lack of understanding and evidence of how investment plans should be designed to not only mitigate risks and enhance community resilience but also be attractive for public and private sector funding and finance (Hallegatte et al., 2020; Omukuti, 2024).
2. Deficits in human and technical competencies and capabilities (including significant data and modelling gaps) in assessing uncertain changes in hazards, exposure and vulnerability under a range of plausible futures and across heterogeneous regions. These limitations are particularly acute at the local government level, where the main responsibilities lie in managing assets and sustaining the provision of essential services (Butler et al., 2015).
3. Prevailing planning and investment approaches are generally siloed within sectors, domains, and departments, which constrains mandates and dis-incentivises consideration of cross-cutting issues and systemic risks (Gorddard et al., 2016).
4. The prevalence of "asset-focused" or "owner/user" focused approaches that ignore i) the cross-scale issues associated with climate change, ii) the systemic causes of vulnerabilities in assets, and iii) the wider cascading effects of the services provided by assets (Chaudhary and Piracha, 2021; Wise R. M. et al., 2022).
5. The generally narrow interpretation and adoption of the concept of "place" in planning and investment decision-making tends to concentrate on assets while often neglecting a fundamental principle of resilience thinking. This principle underscores the necessity of considering scales above and below the focal scale of "place" (Walker, 2020) and must be understood in the context of the scale at which resilience services are needed (World Bank Group, 2021).
6. The emphasis on avoided costs, which is rooted in the idea of value protection rather than value creation, that underpins business cases advocating for investing in resilience. Risk reduction and resilience strategies often struggle to align with business-as-usual (BAU) investment rationales because they typically involve higher initial costs and yield benefits that are delayed, discounted, dispersed, and uncertain in relation to resilience interventions (Mortimer and Lee, 2020).
7. The adoption of narrow economic optimisation frameworks (i.e., profit maximisation, cost minimisation) and measures (e.g., benefit-cost ratios, rates of return) coupled with single scenario pathways. The single scenario option, even when assessed through more elaborate economic tools (e.g., Social Cost-Benefit Analysis) for investment decisions, often constrains the problem framing and the solution space (Tasri et al., 2021; Lempert, 2014).

The consequence of these limitations is that regions are locked into vicious cycles of disruption, repair, and recovery back to BAU (Maier et al., 2016). There is little incentive or capacity to access investments aimed at interrupting these vicious cycles by identifying more strategic and innovative interventions that mitigate disaster risks and create value through resilience. This poses significant challenges for local and regional authorities, which encounter severe funding shortages and rapidly escalating costs (Zhang et al., 2020; Dickman, 2021; Ahmed and Ledger, 2023; Cook, 2024). Even when there is a desire to invest in climate-resilient planning or adaptive capacity, there are few established frameworks or legislated requirements.

Federal and state governments in Australia have recognised the urgent need to reform and enhance the nation's capabilities and

1 In this context, resilience is defined as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UNDRR, 2017). Although "risk management," "adaptation," and "transformation" are included in this definition of resilience, it is often helpful to explicitly refer to each of these elements to ensure the relevant communities and policy environments responsible for each element understand the relevance and implications for them.

investments in adaptation and resilience planning and practice (NEEMA, 2024a), aligning with the Sendai Framework for Disaster Risk Reduction 2015–2030 and its emphasis on improved risk governance and investment in risk reduction (UNDRR, 2,107). Some of these responses have included the creation of the Disaster Ready Fund (NEEMA, 2024a), the Drought Resilience Fund (DAAF, 2025), the reform of the National Disaster Recovery Funding Arrangements (NEEMA, 2024b), the development of the second National Action Plan to implement the National Disaster Risk Reduction Framework (NEEMA, 2024c) and the establishment of the Hazards Insurance Partnership (NEEMA, 2024d). Foundational to all of these is the principle that interventions in resilience and adaptation need to be place-based, tailored to local and regional contexts, and informed by local values and priorities (Buchtmann et al., 2023; CEEW, 2024).

In this context, our study aimed to enhance the capabilities of local governments and stakeholders to conduct multi-scale, place-based risk and resilience assessments of natural and built infrastructure assets amid uncertain changes in climate and socio-economic trends, thereby informing strategic planning, prioritisation, and investments. Critical elements of this capacity building also involve exploring and trialing governance arrangements that could enable multiple LGAs and state agencies to coordinate their efforts more effectively. The concept of resilience investment at the regional level is enhanced by fostering collective understanding and strengthening capabilities through the involvement of a broader group of stakeholders, particularly local governments, in decision-making.

Asset management decisions are generally based on factors such as user feedback, condition, usage, age, and eligibility for public grant funding. This approach tends to reinforce existing short-term strategies that maintain the *status quo*, thereby limiting opportunities for restoration or enhancements that could build resilience. Consequently, expanding the decision-making process has been identified as a key priority. This expansion would allow for more holistic evaluations of interventions that not only protect existing value but also create new value for a broader range of beneficiaries beyond just direct users and asset owners. This includes making a case for investing in enhancements to natural and built infrastructure based on evidence of delivering multiple objectives and sustaining the serviceability of interconnected asset networks across various scales, rather than focusing on individual assets or specific locations (e.g., a plot of land). By doing so, our approach seeks to overcome the seven barriers mentioned above by moving away from traditional asset management practices and redefining how resilience interventions are identified and implemented to foster place-based resilience and scalability.

We present the case study of Bega Valley Shire, situated along the southeast coast of Australia. This region exemplifies many large heterogeneous coastal areas across Australia facing increasing levels of exposure and vulnerability to intensifying natural hazards due to climate change, while also struggling to secure adequate funding and finance for resilience investments. Although the Shire Council is responsible for managing a range of asset types—including natural, social, economic, and built infrastructure—to ensure the reliable supply of critical services, this project could only concentrate on one asset class due to its scope and funding limitations. Early discussions and analyses of the Shire Council's priorities suggested focusing on transport infrastructure as the central infrastructure type.

Notwithstanding this focus on transport (built) infrastructure, the approach developed and demonstrated in this project is transferable and applicable to all forms of critical infrastructure, including Nature-based Solutions (NbS) approaches. This is because nature can be viewed as a form of critical infrastructure – green and blue infrastructure (terrestrial and aquatic, respectively) – that also provides critical services to support the functioning of social and economic systems (Lim and Xenarios, 2021; Kernaghan and Sturgeon, 2024). Healthy and biodiverse natural environments, for example, have higher capacities to absorb disruptions and respond (adapt or transform) to changes than degraded ones, providing climate adaptation and disaster resilience services to people (Colloff et al., 2016; 2020; Walker et al., 2023). The parallels between green-blue and built infrastructure also extend to their investment challenges, requiring sustained and structured investment and management to prevent degradation and support regeneration. Yet, both struggle to realise benefits in the short term and to demonstrate benefits across various scales. This is particularly true for natural ecosystems and interconnected physical infrastructure, such as road networks, where the benefits experienced by individuals are often realised at great distances from the locations of the assets, mediated through the flow of materials and value along interconnected networks supported by this infrastructure (i.e., benefits can be diffuse and challenging to measure) (AIIB, 2023). For instance, a bridge offers value not only to the two pieces of land on either side of the river that it connects, but also to local, regional, and even national transport, which is a critical service underpinning social, commercial, and emergency management. Similarly, vegetation-covered catchments and riparian zones reduce runoff and erosion, improving water quality and reducing river flow velocity, leading to significant benefits downstream in terms of reduced risk of disasters and water storage and treatment costs. Many of the values and the benefits of investment in resilience that protect, sustain and potentially grow the value of services supported by transport or nature are hidden and typically not factored into investment decisions for resilience. These were key issues identified by the Bega Valley Shire Council that are hindering their ability to develop competitive business cases for investing in transport infrastructure across the expansive area of the Shire. These parallels indicate that the approach and insights presented in the manuscript regarding transport are easily comparable and transferable to natural capital and nature-based solutions for developing resilient investment planning on a regional scale. We also acknowledge the emphasis attributed to this Special Issue on NbS for climate change adaptation, and in this regard, we aimed to demonstrate how the proposed approach can apply to natural and built infrastructure.

The project was conducted between January 2023 and August 2024 as a partnership between the Bega Valley Shire Council and Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO). It was implemented through a range of engagement activities (i.e., interviews, meetings, focus groups and workshops) and was underpinned by a theory of change and monitoring, evaluation and learning framing. Details about the context and the methodological approach are provided in

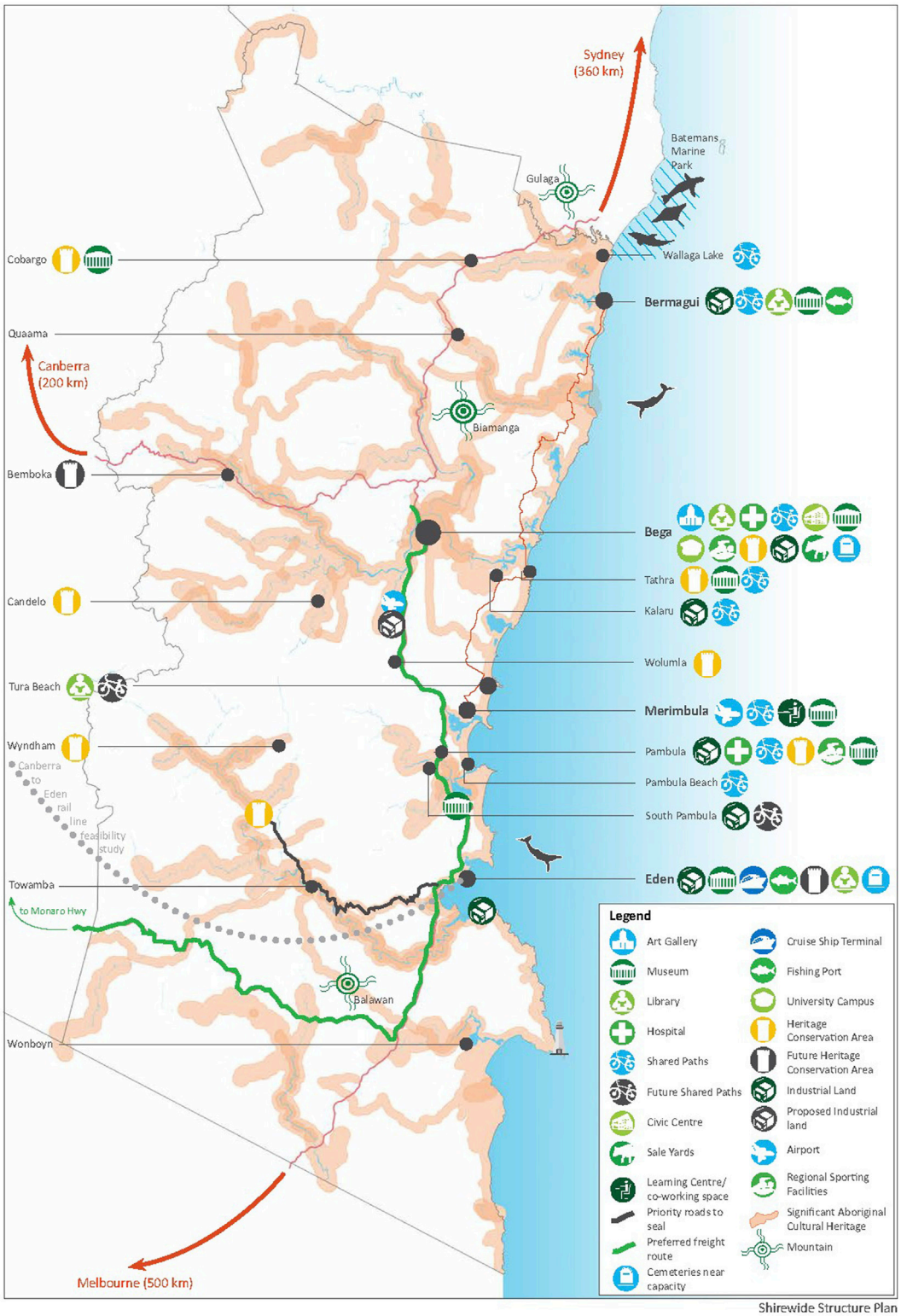

FIGURE 1
Structure plan of Bega Valley Shire on the southeast coast of Australia. Source: BVSC Instement Prospectus, 2023.

the next section, followed by the results section, which illustrates some key insights, products, and outcomes created through the project activities. The results are discussed in the final section to emphasise the lessons learned regarding the approach's effectiveness in addressing key challenges associated with assessing and demonstrating the benefits derived from coordinated strategic investments of widely distributed interventions across networked (natural and built) infrastructure assets. The parallels and

implications for natural capital and nature-based solutions are identified and reviewed.

2 Materials and methods

2.1 The case study of Bega Valley Shire

The Bega Valley Local Government Area (LGA) is situated in the southeastern part of New South Wales (NSW) state. It is the largest LGA in NSW, with a territorial area of 6,280 km^2. The Bega Valley LGA encompasses the largest mountainous range in the country, and is therefore characterised with escarpments, plateaus, and coastal slopes and plains (Brierley and Fryirs, 2000). The range also delineates an extensive network of water basins in eastern Australia. This network encompasses the Bega River, which has a catchment area of 1,040 km^2, covering a significant portion of the Bega Valley LGA. The river drains the upland areas and ultimately discharges into the southern Pacific Ocean after merging with other tributaries. The region receives an annual rainfall of 750–1,000 mm/year, proportionally increasing in the fall and winter seasons (BOM, 2024). However, acute precipitation events have been recorded every season in the last 4–5 years, largely due to the La Nina phenomenon, which has caused wetter conditions in eastern Australia since 2020. The recurrent flood incidents have become more pronounced in the lowlands and the coastline area, which stretches for 225 km and hosts several tourism activities and seasonal accommodations.

The Bega Valley has a relatively low (~35,000) and dispersed population compared to other LGAs in NSW state. Two-thirds of the population live in four towns, where Bega town is the major service hub with a population of 4,368 (in 2021), and the rest of the population is distributed over 12 villages and smaller settlements in rural areas, with much of the population located in small settlements on the coastal fringe. The relatively low population is partly due to the natural landscape, mostly covered (80%) by national parks, state forests, and public reserves, while the lower plains are used for farming. The local economy relies on the forestry industry, agriculture, and manufacturing; however, a large portion of revenues, reaching almost AUD 400 million in 2022, is derived from the over 800,000 annual visitors to Bega Valley (BVSC Resourcing Strategy, 2023a). Figure 1 presents the structure plan of the Bega Valley LGA, as well as the different sites and services provided in the region.

The biophysical characteristics and location along the southern Pacific Ocean expose the Bega Valley LGA to intense weather patterns and natural hazards. Over the last decade, the region has experienced a series of compounding natural hazard events encompassing the unprecedented bushfires that took place over a vast geographic area in 2019–2020, which was followed by 4 years of multiple flooding and coastal inundation events (Kemter et al., 2021). These have led to significant deterioration of critical infrastructure and damage to transport networks across the entire LGA. The LGA has been declared a disaster area approximately 30 times over the last 5 years (2019–2024). The impacts of floods and other hazards (bushfires, landslides, sea-level rise) have significantly affected the local economy, particularly the tourism sector (Bega Community Strategic Plan, 2023b).

There is a major effort from the local government (Bega Valley Shire Council- BVSC) to address the exposure and vulnerabilities of its settlements, infrastructure and communities to climate-induced hazards by developing climate resilience strategies and asset management and financial plans in consultation with relevant stakeholders. For example, the Bega Valley Shire Climate Resilient Strategy 2050 (BVSC Climate Resilience Strategy, 2050) stresses the importance of enhancing its natural, built, and social capital and the significant challenges due to repeated damage and degradation of these from recurrent bushfires, estuarine floods, and landslides. The Climate Strategy provides guidance to asset management and financial planning on maintaining its critical infrastructure assets to ensure the reliable delivery of services to the local community.

The asset classes with the highest capital and maintenance costs are: transport infrastructure networks (e.g., roads and bridges), water supply and sewage infrastructure networks, and parks and recreation (BVSC Community Strategic Plan, 2023b). Indicatively, roads and bridges account for the highest proportion of annual maintenance costs (52% of the total LGA's expenses), with water and sewage infrastructure second at about 26%, and natural parks and recreational infrastructure accounting for about 11% of the annual budget.

2.2 The process of enabling resilience investment in Bega Valley Shire

Increasing the amount of investments in infrastructure resilience at the local level necessitates coordinated changes in LGA's decision-making processes regarding evaluating risks, resilience, and investments in their social, natural, and built infrastructure assets. These changes need to occur in prevailing organisational practices, policies, priorities and knowledge (i.e., the types of knowledge considered in decision-making processes and capabilities to generate or access these) to overcome the limitations outlined in the introduction (Gorddard et al., 2016; Hallegatte et al., 2020; Patel et al., 2020; Barrett and Chaitanya, 2023).

A participatory, multi-scale, place-based approach was used to identify the values and vulnerabilities of infrastructure assets across the Bega Valley Shire and create investment options and pathways for local and regional actors to implement to mitigate risks and enhance resilience. The approach comprised three phases of activities involving iterations of stakeholder engagement (i.e., information and data gathering) and analysis, as illustrated in Figure 2, and will be more thoroughly described in the following sub-sections. The phased approach adopted in the project was informed by the Enabling Resilient Investment (ERI) initiative (Wise R. M. et al., 2022). The ERI initiative is an applied, systems-based R&D framework in Australia introduced in various regions. The ERI involves methods and processes for: i) collectively developing understandings of the interacting root and proximate causes of vulnerability of people, infrastructure, and services to natural hazards, and ii) generating multiple options for mitigating disaster risks, building resilience, and informing adaptation and investment pathways for local communities under scenarios of change.

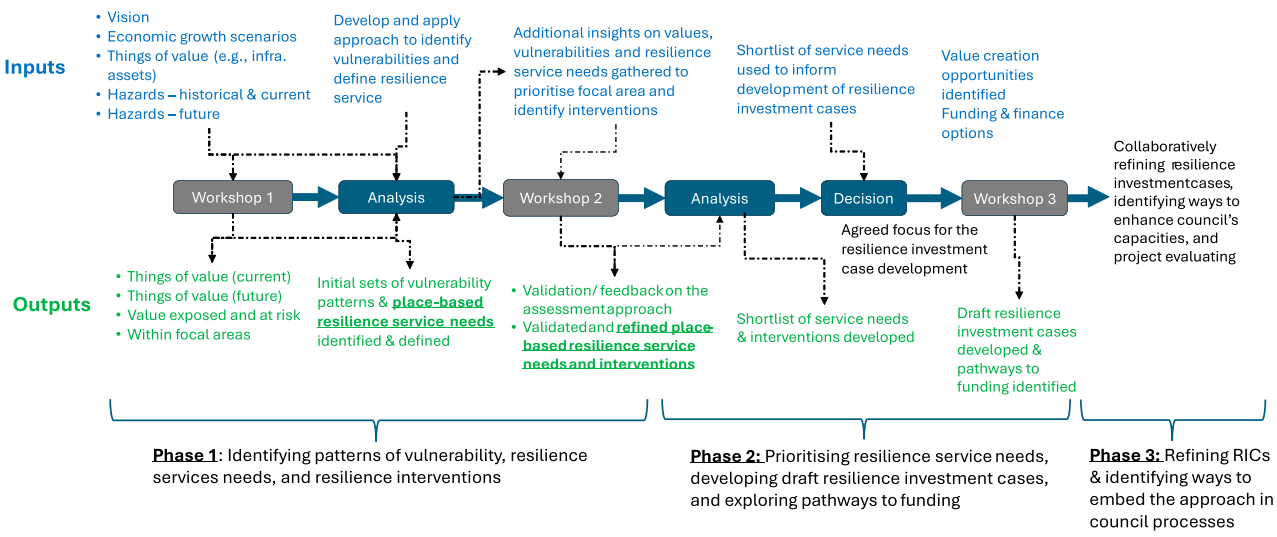

FIGURE 2
Roadmap of developing Resilient Investment Cases in Bega Valley Shire. Source: Authors.

Central to the ERI methods and practices is adopting investment, systemic risk, and value creation perspectives throughout the engagement, assessment, and implementation activities, ensuring that these are carried out with a focus on place, including the multi-level and multi-scale dimensions of that place. The ERI approach draws upon almost two decades of applied R&D activities in complex settings applying and developing innovative approaches to systems thinking, resilience, climate adaptation, sustainability and transdisciplinary science, and knowledge co-production (Wise R. et al., 2022). More information on the ERI approach and its theoretical foundation can be found in Supplementary Material S1.

The three phases of the approach developed in this Bega project were focused on: a) collaboratively assessing vulnerabilities and resilience service needs across the region to generate options and opportunities for mitigating risks and building resilience (workshops 1 and 2, Figure 2); b) exploring pathways to funding through the development of resilience investment cases (workshop 3, Figure 2); and c) co-designing proposed investment cases and exploring mechanisms for incorporating the approach into the Council's operational structures and processes (workshop 3, Figure 2).

The first workshop targeted senior management from the Bega Valley Shire Council (BVSC) who are involved in decision-making. We also invited individuals from BVSC who focus on finance, asset management, planning, and data analysis, as they play a crucial role in enabling local policies in the region. Additionally, representatives from various local associations, community groups, utilities, emergency services, and the business sector were invited to the workshop to better comprehend the background situation before initiating the resilience investment planning process. We included neighbouring LGAs and relevant state government agencies to broaden perspectives and foster collaboration. This approach aimed to enhance understanding and build capabilities across the region, facilitating the future scaling of our strategy. First Nations groups from the Bega Valley Shire were also invited to participate, showcasing existing interventions for hazard prevention, particularly regarding bushfires through prescribed burning, often referred to as "cultural burning" or "cool burning." Indigenous communities have employed this practice for thousands of years to maintain healthy ecosystems and biodiversity, typically involving smaller, cooler burns conducted at specific times of the year (Smith et al., 2021).

In the second and third workshops, we focused on narrowing the participant groups by placing greater emphasis on representatives from BVSC, the utility, and the business sectors. The aim was to gradually identify and develop interventions for resilient investment planning by assessing their impacts on utilities and essential business activities. The same individuals from BVSC, utilities, local government, and businesses were invited to participate in all three workshops. The workshops were held from September 2023 to March 2024 and took place approximately every 2 months to allow for reviewing, analysis, and preparation arrangements.

2.2.1 Workshop 1- understanding the context of values, vulnerabilities, and options for resilience

The primary objective of Workshop 1 was to reach a consensus regarding a vision for a climate-resilient Bega Valley and identify the areas of value and vulnerability within the Bega Valley Shire. The first workshop was composed of 34 participants from 18 different organisations, including representatives from the Bega Valley LGA - consisting of nearly half of the participants (15), local community representatives from environmental and emergency management associations (4), neighbouring councils (5) and state government (NSW) (3), utility services (telecommunications and energy) (3), industry (dairy, oyster farming, tourism) (2), and academia (1). The representatives of the First Nations have not participated in person in the first and the other workshops; instead, their viewpoints on values, vulnerabilities, and resilient interventions have been conveyed through the Council, which conducts regular meetings

with the relevant groups. Six roundtables with equal numbers of facilitators were set up to identify current and future values and vulnerabilities in the Bega Valley region. We drew upon visions previously developed by the BVSC related to economic development, circular economy and climate adaptation to help participants reflect on the values important to the community, particularly in the context of sustaining livelihoods under increasing climate and disaster risk (BVSC Climate Resilience Strategy, 2021).

A multi-hazard risk analysis was conducted to identify the most exposed and vulnerable areas and infrastructure assets (hotspots) to natural hazards across the region at the time of workshop (2023) and over the next 35 years under a changing climate. The time horizon of 35 years (2023–2058) was chosen to align with the investment horizon of investors motivated to create beneficial outcomes for people and place in the short to medium term. This is commonly used for socioeconomic scenarios and climate projections when evaluating investment decisions (Bryan et al., 2016; Szetey et al., 2021).

The multi-hazard assessment was based on the extent and measure of intensity of bushfire, estuarine inundation, and riverine floods, using the best available publicly accessible datasets from the NSW government. The data showed significant variability in how hazards were expressed. Indicatively, flood data indicated the extent of flooding for different recurrence intervals, bushfire hazard levels were classified based on vegetation type, while estuarine inundation data displayed inundation extents corresponding to various sea level rise scenarios. To establish a common hazard index, each hazard was categorised into levels of susceptibility (low, medium, and high), further developing an aggregate multi-hazard susceptibility index comprising nine susceptibility levels. The intention was to enable workshop participants to visually perceive (on printed maps) and discuss the relative hazard susceptibility levels across the Bega Valley region without resorting to overly technical terminology. Initially, the workshop participants were presented with single-hazard maps to examine the impacts of each hazard on the region, followed by printed versions of the maps that illustrated the multi-hazard susceptibility index. More information on the approach used to assess hazard susceptibility levels is presented in Supplementary Material S2.

Two exploratory socioeconomic scenarios were also developed for Bega Valley Shire, depicting two plausible futures for the welfare and livelihoods of people in the region. Exploratory scenario analysis is widely used in situations experiencing large and uncertain changes in socio-economic conditions and spatial organisation due to complex interacting drivers such as geopolitical dynamics, migration and demographic change, climate change, and energy transitions (i.e., technological disruption) (O'Neil et al., 2020; Wise et al., 2024). The first socio-economic scenario described a future of high population growth in regional NSW driven by the assumption of high levels of climate-driven refugees, which stimulates economic growth and regional investments in Bega Valley LGA. The second scenario depicted a lower population growth in NSW and a trend of investments being diverted into growing megacities, resulting in economic degrowth in the Bega Valley LGA, and other regional areas across NSW. The data sources for the scenario development were derived from the BVSC reports, which included strategies, planning, and evaluations. We also introduced elements from the Plausible Divergent Futures scenarios created by the New South Wales Department of Premier and Cabinet to reflect population, migration, employment, industry, and settlement patterns within the state and wider Australia (NSW, 2023). Another source came from scenarios developed in community workshops organised by CSIRO in Bega Valley LGA in 2021 to comprehend the social sentiment in the aftermath of the black summer fires in 2019/2020. A more detailed description of the data sources is presented in Supplementary Material S3.

The participants of Workshop 1 were asked to identify current (2023) and future (2058) values and vulnerabilities based on understanding single and multi-hazard susceptibility and the two different socioeconomic scenarios. The values were intended to represent the participants' most significant individual and community-related aspects by also underlying their concerns about climate-induced hazards. The participants were also encouraged to plot the current and future values and vulnerabilities on the multi-hazard maps provided in the workshop.

The findings from Workshop 1 were geocoded to establish spatial reference points for the valued elements and vulnerabilities identified by participants. Following this, additional information gathered through the project team's synthesis and analysis was linked to the geocoded locations. The geocoded data regarding valued elements and vulnerabilities, alongside the hazard data layers and other contextual information such as demographics and council infrastructure, were visualised in GIS format and analysed to determine spatial patterns and hotspots of exposure and vulnerability. This and other sources of information, such as strategic economic development priorities and climate adaptation actions, were utilised to determine the needs for resilience services.

We further organized the values and vulnerabilities into different pattern to better understand the significance assigned by the participants to various components and to identify potential similarities and common trends throughout the region. The patterns were used to define the nature of the resilience issue–a connectivity issue, a servicabilty issue, or an issue stemming from a demographic or economic driver. The identification and classification of the patterns were data-driven, using the values and vulnerabilities captured in the workshop. There was also a cross-checking with the relevant literature on patterns development and hazard risk management to better align with similar theoretical frameworks (Ward et al., 2020; Sung and Liaw, 2021). The patterns' frequency was further aggregated and standardised (0–1) to detect the significance attributed to each of the above classifications. Using both value and vulnberabilty, the pattern frequency and location in the Bega Valley, the spatial hotspot data together with the LGAs strategic objectives to meet resilience service needs, four areas with the highest current and future vulnerability and impact on community services were identified. These areas were demarcated and printed to be reviewed by the participants in the second workshop.

2.2.2 Workshop 2 – Evaluating and expanding set of interventions to address resilience service needs

The primary aim of the second workshop was to identify and prioritise interventions that would decrease exposure and

TABLE 1 Types of interventions and assets for reducing disaster risks and building resilience in Bega LGA.

Intervention categories	Description
Asset Hardening	Improving the technical capacity/structure of an asset to withstand different hazard types
Service Hardening	Improving the services provided by an asset to withstand different hazard types
Asset/Service Reliance	Reduce reliance on asset/service by increasing coping capacity/demand management/proposing alternative options
Systemic changes	Introduce policy changes to increase asset/service resilience
Asset classes or Infrastructure types	
- Road Network (e.g.,,roads/bridges) - Energy Systems (e.g., power lines) - Water Supply (e.g., water treatment plant) - NbS (e.g., vegetation management) - Communication Systems (e.g., transmission towers) - Commmunication Facilities (e.g., evacuation centres) - Large Infrastructure (e.g., ports, airports)	

Source:Authors.

vulnerability in the four hazard-prone areas defined in the first workshop. The workshop comprised 31 participants, with the majority (22) derived from BVSC. Representatives from the state government (New South Wales, four participants), utilities (3), and the business sector (3) were also involved. This workshop provided an opportunity to present participants with all the data and insights—particularly the patterns of vulnerability and the identified service needs—gathered from the first workshop. Participants were encouraged to contribute values and vulnerabilities that might not have been highlighted in the first workshop and propose interventions to address the service needs of communities and mitigate vulnerabilities. They could suggest more resilient infrastructure (e.g., enhancing the road network) or management aspects related to NbS approaches (e.g., improving vegetation management).

The participants were asked to indicate the proposed interventions on the maps in the four suggested areas identified in Workshop 1. The final list of interventions was organised according to the resilience enhancement objectives proposed by the workshop participants, as shown in Table 1. The interventions were also categorised by asset types to provide a more detailed description of each intervention's characteristics.

We subsequently developed a set of criteria to assess and prioritise the four candidate service need areas identified in Workshop 1, based on the evaluation of the proposed interventions in each area. The rationale for the area prioritisation was that the Council wished to concentrate on two areas by also narrowing down the potential interventions for each area due to budgetary and human capacity constraints.

In assessing the four candidate areas, we introduced criteria related to the potential improvement of resilience to hazards through interventions in each area and the economic benefits and co-benefits that may result from their implementation. We also developed criteria to capture the alignment of the suggested interventions with the strategies and plans of the Bega Valley LGA and the wider region. Another set of criteria responded to the technical feasibility of the suggested interventions as adequate responses to hazard-prone and vulnerable service-need areas. The relevance of the criteria was documented through a) regional, national and federal policy documents of Australia assessing place-based interventions for hazard risk reduction (BVSC Delivery Program, 2022b; BVSC Community Strategic Plan, 2023b; Victorian Government, 2021; NSW, 2022; NSW Department of Planning and Environment, 2022; CEEW, 2023), b) literature review (Ishiwatari and Surjan, 2019; Newth et al., 2021; Jones and Tubeuf, 2022; Okuda and Kawasaki, 2022; IMF, 2024) and c) input from the second workshop on the suitability of suggested interventions. The criteria evaluation was based on feedback for the suggested interventions during the second workshop and input from experts at CSIRO and BVSC with knowledge of disaster risk management. The criteria developed for evaluating the candidate service-need areas are presented in Table 2, which also displays a brief description and the data source.

The ranking of the four service-need areas and the groups of interventions was conducted through the Visual PROMETHEE software, which combines the PROMETHEE multicriteria outranking method with Geometrical Analysis for Interactive Assistance (GAIA). The suggested approach has already been implemented in various fields like energy, manufacturing, building materials and transportation for the prioritisation of options and solutions on research and development initiatives (Macharis et al., 1998; Anagnostopoulos et al., 2003; Dagdeviren, 2008; Prvulovic et al., 2011; Nasiri et al., 2013). In disaster risk management, the outranking PROMETHEE method is proposed as suitable because of its ability to cope with heterogeneous criteria affecting hazard-prone areas, simplicity, ease of use, and transparency of the outranking process. In addition, there is a wealth of literature on the integration of multicriteria techniques with spatial analysis for the selection of place-based solutions, as occurred in our study (Mareschal and Brans, 1988; Malczewski, 1999; Marinoni, 2005; Knezic and Mladineo, 2006). For the assessment of interventions in the four hazard-prone areas of Bega Shire, we considered equal weighting among all criteria to avoid the asymmetrical influence of certain criteria over others.

2.2.3 Workshop 3 – identifying opportunities to create value

The third workshop was attended by a smaller number of participants (23), with the majority (15) representing BVSC and also participating from neighbouring local governments (3), New South Wales state government (2), and utilities (3). The areas prioritised using the PROMETHEE multicriteria outranking method were presented in the third workshop, along with lists of interventions included in each area. The interventions were geolocated on maps, and the participants were requested to provide more detailed information on the features of each intervention (e.g., exact location, material, and capacity). The potential interdependencies between interventions were also explored (e.g., improving vegetation management to mitigate the risk of bushfire impacts by considering eco-tourism related activities).

TABLE 2 Evaluation criteria for assessing the interventions in hazard-prone areas of Bega Valley LGA.

No.	Criteria	Criteria description	Data source	Assessment
1	Risk Reduction and Resilience benefit	Potential to deliver risk reduction and resilience benefits to hazards	LT, WS2	CSIRO/VAP
2	Co-benefits in times of stability and tourism season high season	Potential to deliver co-benefits during times of stability (without hazards) and during times of high demand (peak tourist season)	R, WS2	CSIRO/VAP
3	Co-benefits across movement scales	Potential co-benefits of the intervention across movement patterns scales (to/from, within and through)	R, WS2	CSIRO/VAP
4	Co-beneficiaries beyond DRR	Potential benefits of intervention for transport users and journey types	LT, BVSC	CSIRO/VAP
5	BVSC strategies and plans	Alignment with the main BVSC strategies and plans	R, WS2	BVSC
6	Regional strategies and plans	To what extent does the suggested intervention contribute to regional strategies	R, WS2	BVSC
7	Community Acceptance Social license	To what extent the suggested intervention can have the acceptance of the community and stakeholders when suggested for realisation	LT, R	CSIRO/VAP
8	Funding Potential	To what extent is a suitable level of funding available/can be secured to fund the cost of the project	LT, R	CSIRO/VAP
9	Benefits at least one other LGA	Potential benefits for neighbouring LGAs (investment cases to be developed will benefit two or more LGAs.)	R, WS2	CSIRO/VAP
10	Data and knowledge availability	To what extent the relevant knowledge, data, and information is available for the realisation of the project	LT, WS2	CSIRO/VAP
11	Effort/timeframe Needed	The scale of analysis (area, number of features) is commensurate with project effort and timeframes	LT, WS2	CSIRO/VAP
12	Complexity	Degree of complexity for the accomplishment of this project	LT, WS2	CSIRO/VAP

Note: LT , input from literature review; R, Input from local/national/federal reports; WS2, Input derived from Workshop2; CSIRO/VAP, Evaluation conducted by CSIRO/VAP, team; BVSC, Evaluation conducted by BVSC, representatives.

The participants were then asked which interventions could address the resilience service needs of each area, while also benefiting the wider Bega Valley Shire by developing economic opportunities and creating value within the community. The opportunities refer to potential investments that can be created due to the realisation of an intervention or a combination of interventions and have the potential to add economic value. The interventions could contribute to creating a direct economic opportunity (e.g., increased property values because of improved road network) or indirectly through other assets and services developed (e.g., new bicycle lanes alongside the roadway or wildlife crossing due to the road widening intervention). The interventions were suggested for a period of 35 years (2023–2058) to coincide with the socioeconomic and climate scenarios developed in the previous workshops. For the assessment of the economic opportunities emanating from the suggested interventions, we developed a valuation framework as presented in Figure 3.

On the cost side presented in Figure 3, we initially estimated the incurred costs for developing the relevant project (e.g., construction of a new bridge with reinforced concrete). BVSC asset and infrastructure management experts provided capital (CAPEX) and operational (OPEX) expenditures for each intervention. We further introduce the terms "value at risk" and "value potential" to identify the benefits created through potential opportunities that could be created by reducing hazard susceptibility or vulnerability or enhancing resilience at a regional scale. The value at risk (VaR) is widely used in the insurance sector to identify the amount of possible financial losses in a certain time period and the probability that the defined loss will occur (Basak and Shapiro, 2001; Abad et al., 2014; Li et al., 2017; Richards, 2021). In our case, VaR represented the product of the probability of a hazard occurrence in Bega (over the 2023–2058 period) and the potential averted costs due to more resilient standards. In other words, an economic opportunity based on the suggested resilient interventions could decrease the expected damages from future hazard occurrences and essentially create benefits for the local community. We used a cost-avoidance approach to evaluate the benefits of reducing damages in the suggested interventions. The hazard occurrence probabilities in the region were provided by a firm conducting climate risk analysis through the estimation of hazards and extreme events based on downscaled climate scenarios (XDI, 2024).

The "value potential" was captured through benefit-transfer analysis by introducing hypothetical market values (Willingness to Pay-WTP) estimated from areas and communities experiencing similar conditions (Schrödl and Turowski, 2014; Colombo et al., 2023). The WTP values accounted only for the potential benefits to residential communities in the Bega region due to the lack of available data for other assets and services. We also introduce elements from Collaborative-Valuation-Frameworks (CVCs) to assess the rate of agreement of the BVSC participants on the benefit transfer analysis and the capturing of other economic values proposed by their side (Austin and Seitanidi, 2012; Brozović and Tregua, 2019). We further assessed the benefits of the construction phase of the relevant interventions (e.g., employment, accommodation of working force) through a gross-margin analysis (Nariswari and Nugraha, 2020; Evmenchik et al., 2021).

In Table 3, we present the most prevalent categories related to value at risk and value potential for disaster risk reduction and resilient

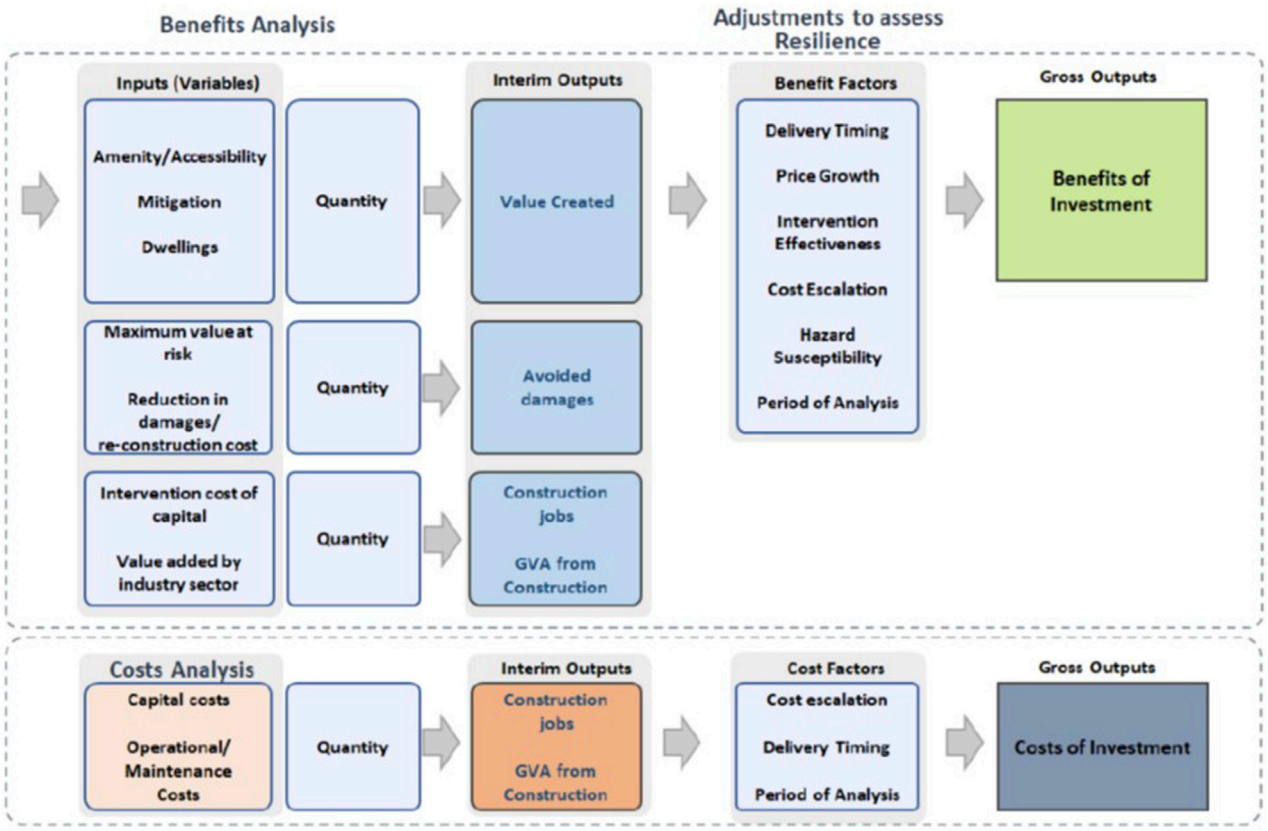

FIGURE 3
Valuation and cost-benefit analysis framework used to assess and inform resilient investment options and pathways in Bega Valley Shire. Source: Authors.

TABLE 3 Value at risk and value potential categories and assessment techniques.

Category	Description	Assessment
Value at risk		
Asset Restoration	Replacement of discrete assets to pre-disaster conditions	Cost Avoidance, Benefit Transfer
Environment and Heritage	Impacts on critical ecosystem goods and services	Contingent Valuation, Benefit Transfer
Aesthetic and Heritage	Impacts on assets of aesthetic and historical value	Contingent Valuation, Benefit Transfer
Value Potential		
Service Performance	Increase performance and capacity of essential social services	Contingent Valuation, Benefit Transfer
Economic Uplift	Increase economic investment, commerce and employment in property and assets	Market Value, Contingent Valuation, Benefit Transfer
Community	Increase wellbeing and sense of security from natural hazards	Contingent Valuation, Benefit Transfer

Source:Authors.

investment planning in Australia, along with the assessment techniques usually applied to capture the relevant values (Infrastructure Victoria, 2016; PwC, 2017; Victorian Government Value Creation and Capture Framework, 2021; AIDR, 2024). As noted above, in our analysis, we assessed the economic uplift in residential properties (value potential) and asset restoration (value at risk), while the other categories were omitted due to unavailable data.

The economic analysis also considered the performance of these opportunities over an investment period of 35 years, as per the timeframe of the climate and socioeconomic scenarios. We calculated the anticipated costs and benefits by introducing a range of plausible discount and growth rates per the region's economic outlook and the effects on projected property values. We also estimated future hazard probabilities over the next 35 years by analyzing historical data, as described in Supplementary Material S4. Additionally, we projected the potential impact of these hazards based on the RCP 8.5 and RCP 4.5 climate scenarios by downscaling them for the region.

2.2.4 Project monitoring and evaluation

Workshop surveys were conducted to support the monitoring, evaluation, and learning framework of the project. Participants were

requested to reflect on aspects that proved less effective, articulate their requirements for further development, and identify practices they believed could be scaled to other local government entities. The objective was to evaluate participants' satisfaction following each workshop by also identifying the elements that contributed to their capacity enhancement and supported their respective roles.

The workshop survey approach also enhanced knowledge sharing within the project partners and facilitated necessary adjustments to project implementation. Along with the workshop events, smaller working groups were also organised with the assets managers and planning teams of the BVSC between workshops two and three to ensure the gradual integration of the projects' findings into the operational planning of the Council. Upon completion, an external evaluation team performed a thorough project assessment, enabling effective and balanced reporting on project activities, outputs, and outcomes. Furthermore, the external evaluation examined whether the project fulfilled stakeholder needs and explored the potential for replicating and scaling the project model to additional regions.

3 Results

3.1 Workshop 1- outcome

In the first workshop, 208 current and future values and vulnerabilities were identified by the participants and clustered according to the most prevalent patterns as described in the Workshop 1 methodology. Four pattern groups were formulated based on the values and vulnerabilities suggested by participants about a) the connectivity of Bega Shire with other regions, b) the need to sustain selected services, c) the attention on local economic activities, and d)the role of demographics about housing and settlement trends, as presented in Table 4.

Figure 4 illustrates the frequency of current (2023) and projected (2058) values and vulnerabilities proposed by the participants, summarised in the four patterns above in a standardised (0–1) format as mentioned in the methodology. The participants emphasised the serviceability patterns for the current year (2023) and anticipated values for the future (2058), along with the identified vulnerabilities. They also voiced concerns about the region's future connectivity and economic activities. Furthermore, the potential vulnerabilities facing the population and the housing sector in Bega were also discussed.

After consultations with BVSC, four areas of interest encompassing various values and vulnerable areas were prioritised as presented in Figure 5 with rectangular frames. An intentional overlap between the four areas was designed to demonstrate the interconnections of values across the wider region and the scale of vulnerability in the entire LGA. For example, a flood-vulnerable coastal area could impact travel to remote settlements along the coastline and affect commuting between the northern and southern parts of Australia's east coast. Participants in the first Workshop found the activities and insights thought-provoking and relevant to their work. They appreciated learning about the other participants' differing values, perceived vulnerabilities, and risks. From the workshops and subsequent analysis, the transport infrastructure (council's roads and bridges) and their fundamental role in supporting life and economic activity in the region during times of stability and throughout natural hazard events emerged as the priority resilience service need.

3.1.1 Workshop 2- outcome

The suggested interventions were geocoded and grouped according to the resilience improvement classification described in the methodology, as shown in Figure 6. As expected, there was a high overlap between the values and vulnerabilities depicted in Figure 5 and the suggested interventions' locations. In most cases, the interventions were proposed to sustain the current and future values and increase the resilience of the relevant assets. The interventions were proposed as a single activity to improve resilience, but also as a bundle of activities (e.g., improving vegetation management across the road network and creating permeable road pavement). Figure 6 illustrates the types of interventions suggested by participants in the four areas discussed during Workshop 1, as denoted by the rectangular frames.

Figure 7 presents the multicriteria analysis's ranking in numerical and diagrammatic format for the four candidate areas based on the performance of the suggested interventions identified in each area. The table presents the scoring of each area on a numerical scale 0–100 (min-max) in the fourth column, while a diagrammatic format with relative ranking values is also presented.

Figure 8 illustrates the two highest-ranked areas identified through the MCA process. The top priority is assigned to the entire region (see Figure 7 "Larger BVS") – the largest area depicted on the left side of Figure 8. This area underscores the significance of Bega Shire's connectivity *via* the main transport corridors to the rest of the country. The second prioritised area refers to the coastal settlements (see Figure 7 "StringSap"), represented as a red rectangle on the side of Figure 8. The coastal area highlights the dependence of isolated coastal communities on a single road network that is often overloaded during holiday periods that coincide with the high-risk weather season and bushfires.

3.1.2 Workshop 3- outcome

The participants agreed on different bundles of interventions to compose a resilient investment case for the two selected areas identified in Workshop 2. As noted in Section 2.2 on the workshops' design, the service needs of each area were perceived through a place-based approach so that each intervention could simultaneously maximise different needs (e.g., a reinforced bridge for flood disasters can also support tourism-related amenities, daily commuting, access to health service, *etc.*). The participants further identified the funding mechanisms to be potentially utilised to realise an investment case and the funding sources to be sought for a proposal, as presented in Figure 9.

The benefits associated with the "values at risk" and "value potential" mentioned in the methodology were compared with the capital and operational costs required to develop each intervention in the two selected areas. After deducting the operational and maintenance costs, the interventions were prioritised based on the highest anticipated economic benefits. In total, 171 economic benefits from 64 interventions were identified in the two prioritised areas (see Figure 8). The interventions were also presented as bundles to more accurately reflect the scale of effect should the resilient investment occur.

TABLE 4 Values and vulnerability patterns identified in workshop 1.

Connectivity	Services	Economics	Demographics
Hazard-prone roads connecting Bega LGA with other regions	Increasing demand for aged care services	Decline in agriculture and aquacultural productivity due to extreme events	Balancing growth between commercial and regional areas
Hazard-prone roads between localities and service areas within Bega LGA	Increasing demand for services in remote areas	Tourism industry decline due to hazards	Need hazard-resilient and affordable housing to meet current and future demand
Hazard-prone residential streets	Need for service coverage during hazards	Support local industries impacted by hazard	Safeguarding dispersed settlements during hazards
Hazard-prone utility assets	Need for community awareness of resilience	Need for circular economy innovation and resilience initiatives	Consider settlement patterns in the context of future hazards and growth

Source:Authors.

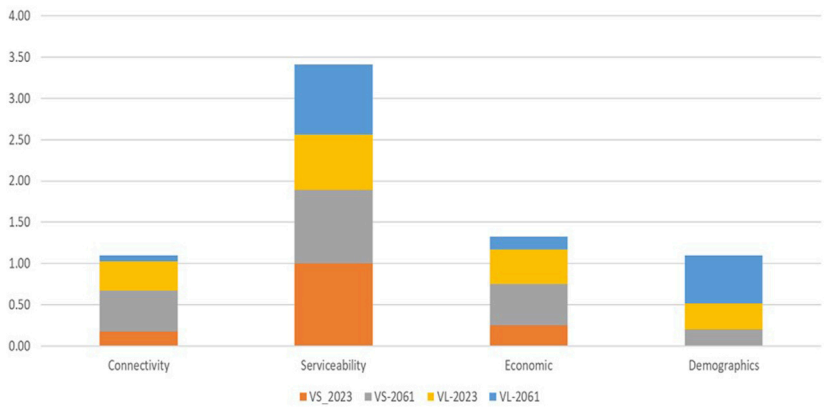

FIGURE 4
Current and future vulnerabilities in bega Valley region. Source: Authors.

An interactive web-based platform, the Resilient Investment Case Explorer (RICE), was developed to offer comprehensive information about the interventions and their associated costs and benefits, including non-economic benefits such as number of jobs and amenity (Figure 10). The platform allowed users to select various intervention combinations as "bundles," enabling them to explore combinations of options for resilience investment.

The dashboard in Figure 10 illustrates the total economic benefits of the top-ranked intervention bundles while highlighting the most vulnerable areas in terms of bushfire susceptibility. The overall economic benefits could reach AUD 622 million if all suggested interventions are undertaken, while additional employment benefits could further enhance the economic development of the Bega Valley Shire. Indicatively, the estimated economic value of the benefits from the increase in residential property values could reach AUD 175 million. This potential increase in residential property values was conducted through the benefit transfer method, presuming similar conditions for properties to which we could confidently attribute these benefits. The benefits derived from the avoided reconstruction costs due to the enhanced resilience of the relevant assets were estimated at AUD 280 million by calculating the avoided road damage and repair costs. Additional benefits included approximately 1,280 direct jobs, primarily in the construction sector, contributing AUD 167 million in Gross Value Added from these employment opportunities. Conversely, the capital and operational cost of all the interventions could reach AUD 400 million and AUD 84 million, respectively.

We further explored the potential economic benefits arising from various additional services and amenities (e.g., recreational activities, business development, *etc.*) that could arise from additional investments in value-creation opportunities related to the suggested interventions throughout the region. In doing so, we identified 55 additional service and amenity investments with benefits ranging from AUD 280 to AUD 560 million. These were estimated using an online database of direct and indirect use values based on contingent valuation approaches developed by Australia's Bushfire and Natural Hazard Cooperative Research Centre (Hazrds CRC, 2024). We did not include the indirect economic benefits in our assessment. The purpose of estimating the indirect economic benefits was to demonstrate that investing in resilience for a networked road system can further offset the costs associated with the investment in resilience. The individual benefits of each intervention, including the cost avoidance from more resilient assets ("value at risk") and the economic uplift ("value potential"), together with the capital and operational costs, are uploaded as Supplementary Material S4.

3.1.3 Overarching resilient investment planning in Bega Valley Shire

Staff members at BVSC reported that their exposure to the suggested approach has assisted them in integrating disaster risk

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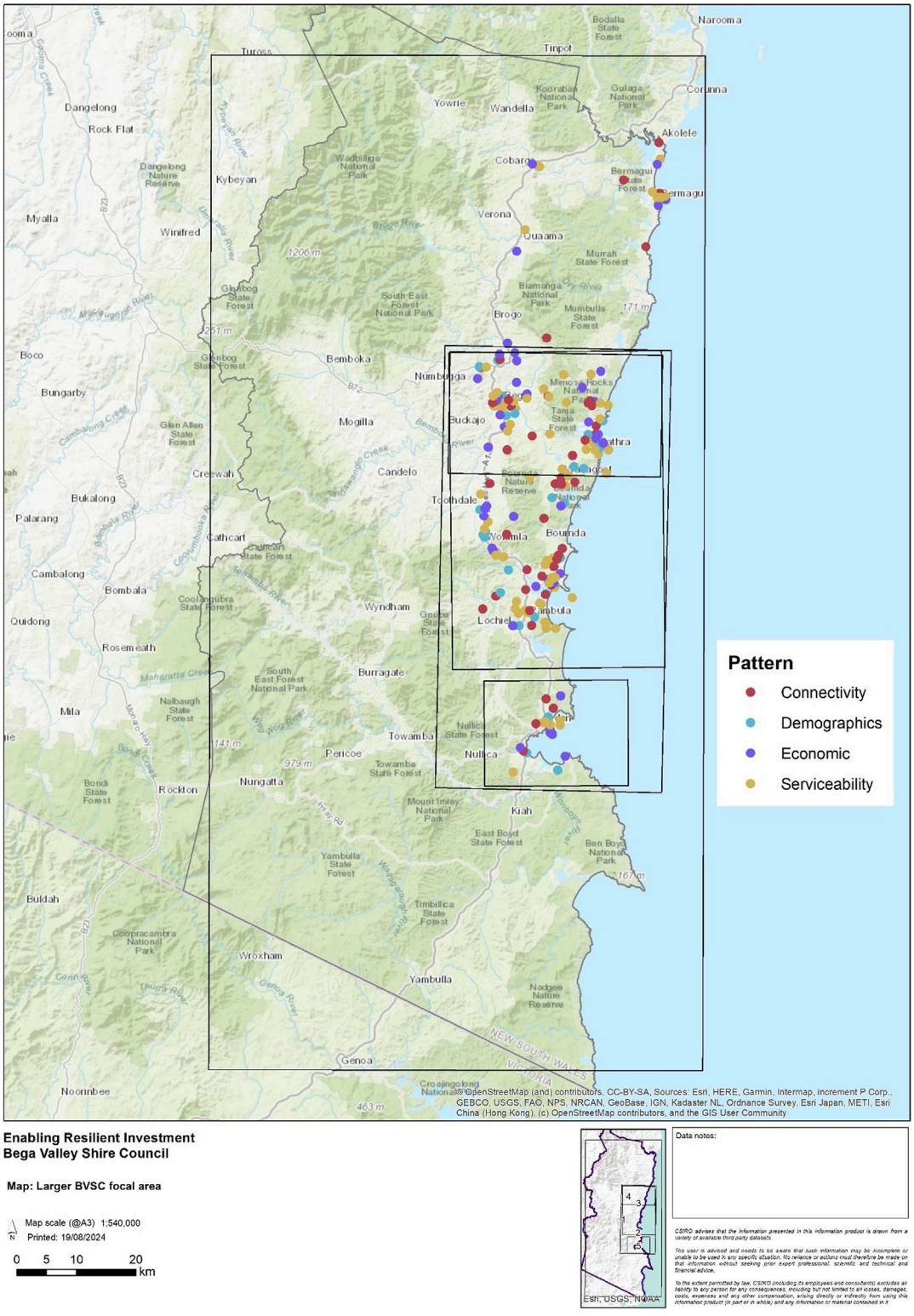

FIGURE 5
Suggested values and vulnerabilities as per the observed patterns in Workshop 1. Source: Authors.

information into their operational processes. They also tested innovative risk reduction and intervention strategies through a systems-based thinking approach. Using the ERI approach and tools, council staff can continuously identify complex risks and recognize the advantages of proactively prioritizing certain interventions to mitigate risks in a network. This proactive strategy is preferred over reactive methods that manage damage to critical infrastructure during or after a disaster.

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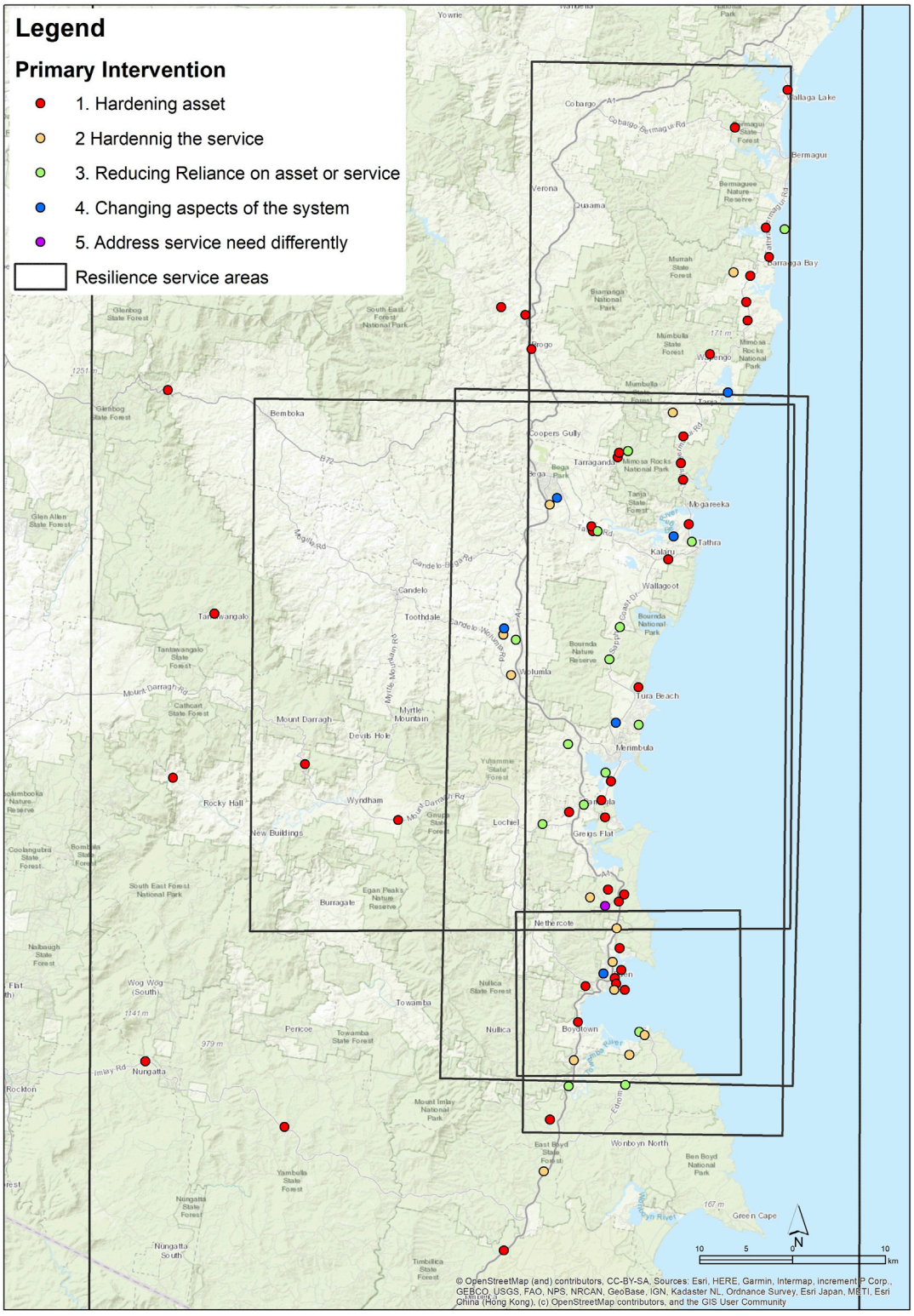

FIGURE 6
Geocoded suggested interventions to enhance resilience in Bega Valley Shire. Source: Authors.

The proposed approach ultimately assisted the BVSC in enhancing their capacity and implementing place-based solutions to reduce local and regional risks while improving disaster resilience. It is noted, however, that by the end of the project, council staff had still not integrated the tools and strategies into their existing planning and decision-making processes. The BVSC aimed to incorporate strategic elements of the ERI approach into their learning management system to continue building their capacity

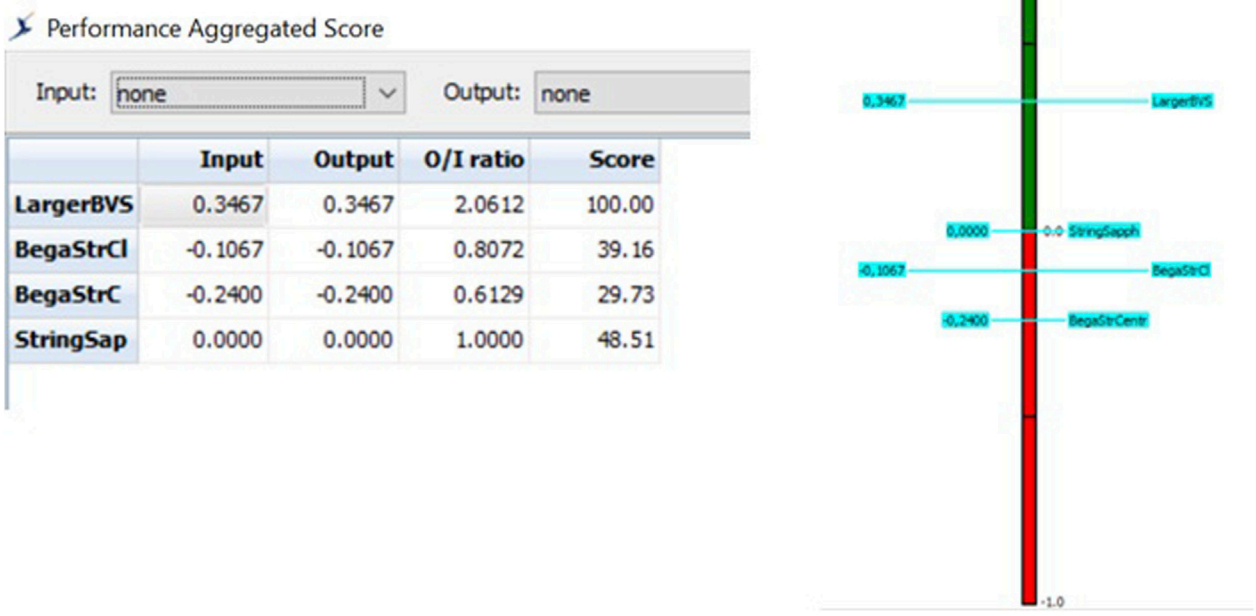

FIGURE 7
Multicriteria Analysis for prioritising interventions and areas in Bega Valley Shire. Note: Larger BVS: The entire region covering the main transport corridors in and out of Bega Shire; Bega StrCl = a region where the Bega town is considered the major center for service provision to coastal and inland communities; BegaStrC = a region where the major town (Bega) is contemplated together with the airport and port facilties as significant infrastructure; StringSap = This region covers the coastal settlements that are largely connected with a main road network.

and embed the approach more systematically. Additionally, the Council planned to conduct ongoing monitoring, evaluation, and learning related to their implementation of the ERI approach to assess its strengths, weaknesses, and areas for improvement. Council staff emphasized that for successful embedding and scaling, further efforts must be made to broaden the enabling environment for key infrastructure projects, which involves engaging with State and Federal governments, critical infrastructure providers, and funders.

4 Discussion

4.1 Climate-resilient investments and NbS implementation

The need for climate-resilient solutions has increased due to the growing frequency, extent, and severity of hazards, along with the growing levels of exposure and vulnerability as populations and regions grow. Various scholars and practitioners have proposed diverse options based on technological advancements, integrated modelling approaches, and elaborate financial tools and mechanisms through theoretical frameworks and applied projects (Maru et al., 2014; Xenarios and Polatidis, 2015; Gallina et al., 2016; Manandhar et al., 2018; Raikes et al., 2020; Meharg, 2023a; b). A major focus is placed on enabling preparedness and prevention for physical climate risks, developing response initiatives (cope and adjust), and recovery efforts (through building back better), by also creating taxonomies for climate adaptation and resilience activities (Carr and Nalau, 2022; Tailwind, 2024).

Our study aimed to develop a transparent and applied research approach for local governments to select the most favourable options and bundles of risk reduction and resilience-building interventions among built and natural capital to meet their needs by providing facilitation and technical assistance (e.g., hazard maps, climate projections, decision support tools, *etc.*) throughout the process. The selection of NbS was among the proposed interventions suggested by workshop participants, mainly representing vegetation management for bushfire and flood hazards. Although vegetation management was not explicitly acknowledged as NbS in the workshops, it was underscored that empirical evidence supports the efficacy of forest-based solutions in mitigating the risk of natural hazards.

The introduction of NbS on disaster risk reduction in both urban and rural contexts has been acknowledged by various policy documents and frameworks in Australia (AIDR, 2024; CEEW, 2024; DFAT, 2024). Also, numerous instances documented in scholarly works and real-world endeavours demonstrate the utilisation of NbS in the country to bolster climate adaptation and resilience at local and regional scales, concurrently fostering community wellbeing (Frantzeskaki et al., 2019; Wang et al., 2022; Debele et al., 2023; Morris et al., 2024a; b). Indicatively, some NbS for flood protection

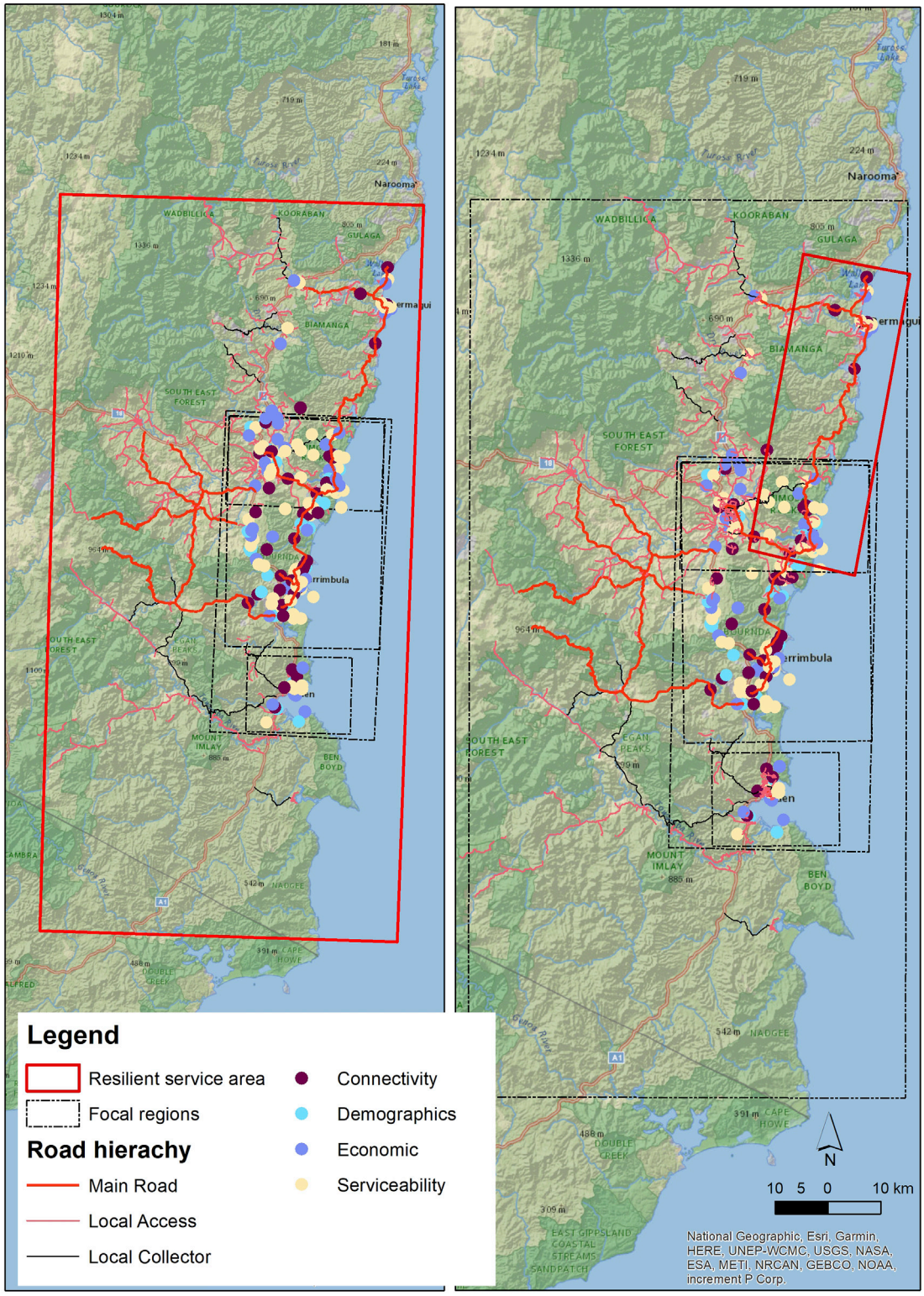

FIGURE 8
Resilient transport corridors (left side) Resilient Coastal Settlements (right side).

in Australia include using green infrastructure with porous surfaces, restoring wetlands and floodplains through geoengineering, and cultivating water-absorbing vegetation (Morris et al., 2019; Christopher et al., 2024). Equally widespread are the NbS for drought adaptation and resilience, such as reforestation and sustainable forest management and the introduction of agroforestry practices to improve water retention and water flow regulation (CSIRO, 2024).

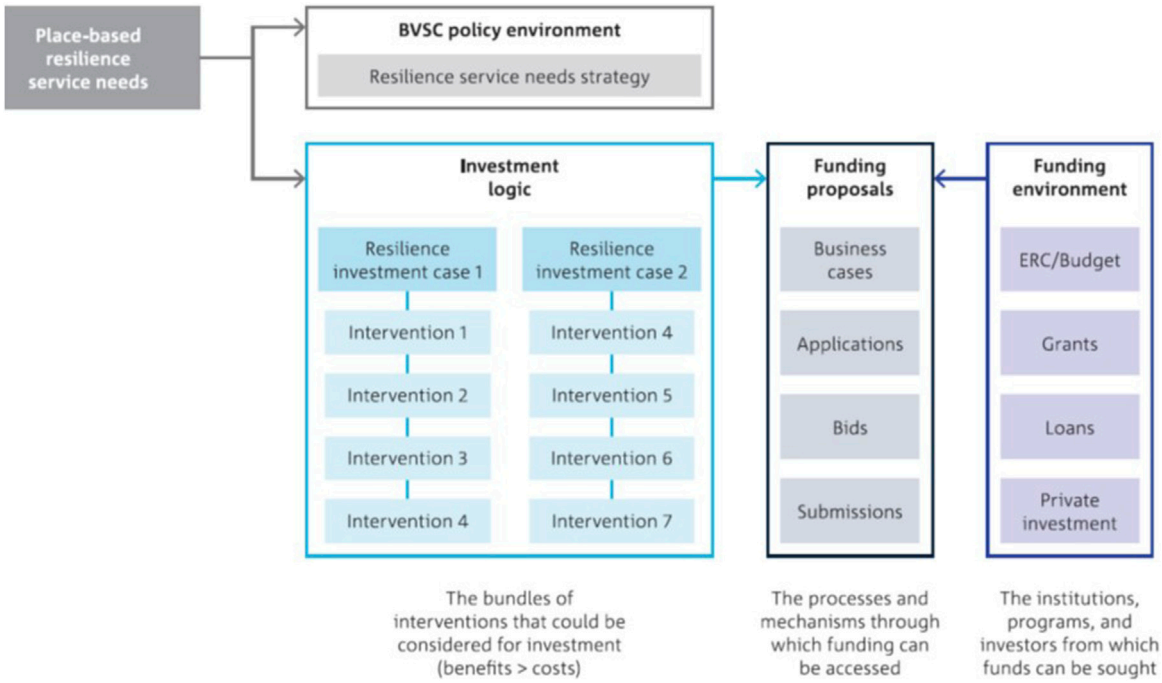

FIGURE 9
Funding Mechanisms and Proposals for developing resilient investments in Bega Valley Shire. Source: Authors.

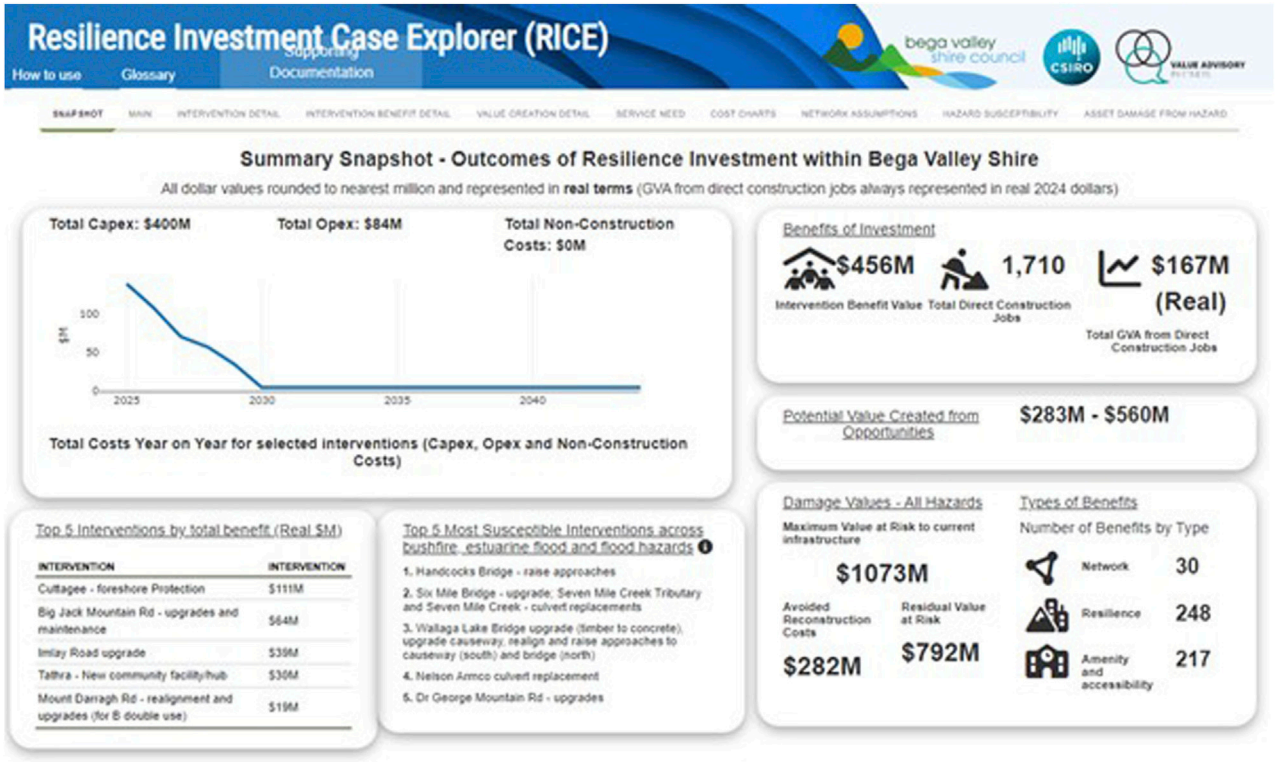

FIGURE 10
Screen shot/grab of the RICE dashboard depicting the prioritised interventions and overall benefits that could potentially be realised from the bundle of interventions included in an illustrative resilient investment case in Bega LGA. Source: Authors.

Most Australian states have introduced NbS to address the impact of bushfires by implementing strategies for vegetation management and endorsing the use of indigenous fire-resistant plant species. More robust NbS includes prescribed burning to reduce fuel loads, stimulate ecological processes, and restore natural fire regimes which has also been discussed in Workshop 2 when suggesting the intervention of vegetation management. Prescribed burning has been applied for many years in Bega Valley and more broadly in Australia for bushfire management and forest regeneration purposes (Russell-Smith et al., 2020; BVSC, 2023). The introduction of NbS to increase resilience to climate-induced hazards has been proven cost-effective in many cases, requiring lower operational and maintenance costs than other proposed options (DFAT, 2024). Multiple benefits to ecosystem services stemming from NbS go beyond climate adaptation and resilience, such as improved air and water quality, wildlife habitat, carbon sequestration, and recreational opportunities (Sangha et al., 2024).

However, various parameters have impeded the implementation of NbS and also other interventions for enhancing resilience against hazards in Australia which has been also mentioned in the second workshop, thereby reducing their effectiveness and expected outcomes. A major challenge often encountered in implementing NbS in Bega Valley and more widely in Australia, was the lack of involvement of local stakeholders and insufficient support from key actors to promote and implement these solutions in the respective areas (Zhu et al., 2023). Prescribed burning has been extensively implemented, particularly following the significant bushfires of the past two decades. Nonetheless, significant concerns exist regarding the weak engagement of local stakeholders, including First Nations groups. Communities from the First Nations that have historically practiced bushfire burning for landscape management are not always involved in the decision-making process. The lack of engagement from Indigenous groups often results from the differing practices between them and state government land management agencies (Smith et al., 2021; Sangha et al., 2024). It was acknowledged, however, throughout the workshops in Bega Valley that Indigenous fire practices were encouraged and implemented after the "Black summer" of 2019–2020, which burnt 5.5 million hectares in NSW alone (ABC News, 2020).

There are also controversial arguments regarding implementing NbS in Australia as suitable interventions for resilience planning in vulnerable systems. For instance, living seawalls have been introduced in the Sydney harbour by installing panels that mimic "microhabitats" to help marine biodiversity while protecting coastal areas from sea level rise (Adapt NSW, 2024). There is, however, criticism of the broader concept of seawall construction due to the obstruction of natural processes and sediment distribution and the underestimation of the scale and frequency of coastal inundation (Morris et al., 2024b). Also, estimating the risk of loss for assets and infrastructure, known as the Maximum Value at Risk (MVAR) in NbS interventions, has been extremely challenging due to the difficulty of estimating the anticipated damages from more intense hazards, which was also undernoted mainly by the asset and finance managers of Bega Council during the project. This uncertainty has burdened BVSC's planning to implement resilient interventions, including NbS, on a large scale and develop resilient mechanisms.

In this study, we aimed to address the considerations mentioned above by creating a clear and transferable process for developing climate-resilient investment cases at a regional level. We organised a series of workshops by initially including a diverse set of local stakeholders and gradually increasing the role of the local government as an enabling authority for the adoption of NbS solutions, among others. The workshops' outcome drove the identification of current values and vulnerabilities and suggested different interventions by allowing local stakeholders and authorities to formulate their views on climate-resilient solutions.

We acknowledge the inherent constraints of downscaling the hazard probabilities in 35-year climate change scenarios and the difficulty of workshop participants comprehending the technical details of these uncertainties. In this regard, we attempted to interpret the technical and quantitative information into simple and qualitative terms. We incorporated the current knowledge of single and multi-hazard risk probabilities in Bega Shire through historical data and global climate scenarios by adopting three main susceptibility levels (high-medium-low) based on publicly available datasets. The participants were mainly tasked with assessing potential interventions in assets and infrastructure that could effectively reduce varying levels of vulnerability without depending on technical knowledge and complex terminology.

The current study has not demonstrated the validity of the proposed approach, particularly in terms of monitoring and measuring specific metrics related to hazard-resilient targets. However, the suggested decision-aiding dashboard can help local governments explore potential interventions, evaluate their anticipated costs and benefits, and support deliberations about what combinations of interventions to prioritise for investment.

4.2 Climate-resilient investments and local governance

Throughout the consultation with the BVSC, it was emphasised that their limited capacity to integrate climate-resilient options into planning was due to budgetary constraints, inadequate expertise, and a lack of awareness of potential benefits. Major attention was given to our approach to involve the local government as much as possible in the co-development of the suggested interventions, prioritising the relevant areas per the needed services, and designing the resilient investment cases.

The working groups, together with the workshops, have also significantly supported the identification of the enablers that could incrementally embed the project's findings into the planning documents and strategies of the local government. The evaluation surveys conducted after the workshops and upon project completion reveal that the BVSC staff are interested in using the tools and processes outlined in the recommended approach. Many participants intended to apply these concepts for strategic thinking, informing funding applications, engaging stakeholders, and developing resilience strategies.

It is acknowledged that the consultation with the Bega Council has identified only the vegetation management as an NbS approach to enhance the region's resilience against hazards. However, we consider that the design and consultation process presented in this study is fundamental for developing resilient investment cases that

could materialise through different NbS options in a further stage. The recommended process addresses research and policy-making questions regarding developing inclusive and co-designed solutions to enhance resilience, specifically emphasising the regional level.

It is also understood that the transportation sector is not commonly targeted for NbS interventions, as indicatively occurs in the natural resource management field. The selection of the transport sector and its associated assets and infrastructure was based on the considerable burden that local governments face, particularly in hazard-prone areas, to maintain the road network effectively. Indicatively, in the case of the Bega Council, more than 50 per cent of the annual budget has been devoted to road maintenance over the last decade due to a series of hazards that have had a major impact on the network.

More broadly, for regions in Australia like the Bega Valley LGA, prone to extreme weather conditions and events likely to be exacerbated by climate change, the need to plan for disasters and safeguard infrastructure vital to community resilience is ever-present. This underscores the urgent requirements for local government planning and risk reduction to actively engage in the contextual understanding of the communities they service. It also entails transcending the narrow definition of resilience and risk reduction solely in terms of the financial impact of material loss by integrating more systemic approaches and service-needs analysis that can assess the current and future needs of the community.

A major challenge to identifying and actioning initiatives that focus on increasing climate resilience in the regions of Australia lies in the disjointed and complex policy environment that governs local government decision-making. The LGAs in Australia traditionally rely on grant funding for substantial capital works to sustain their infrastructure against hazards. The grant funding is often pursued after a disaster occurs, typically alongside heightened demands for disaster response. Consequently, funding for infrastructure upgrades and repairs primarily addresses damage that has already occurred. This is evident in the Bega LGA, where between 2021 and 2024, AUD 2.5 million was spent on emergency works and over AUD 30 million on remediation works from natural disasters affecting transport networks—representing 17.29% of the total capital works expenditure during that period (BVSC, 2021). As a result, the current funding practices tend to prioritise asset renewal over fostering resilience through collective understanding and capability building. The planning approach introduced at BVSC through ERI can facilitate proactive identification of resilient interventions and investment planning by nurturing a discursive social practice in local governance.

Furthermore, there is a growing trend in the country of shifting costs from federal and state governments to local governments. This has gradually transferred workloads and responsibilities to LGAs without corresponding adjustments to resourcing. The factors above contribute to a situation in which local governments and their associated communities bear the brunt of the impact of natural disasters, both during the event and in the subsequent recovery phase. This often necessitates significant recovery efforts despite limited access to the resources and legislative capacity required to make the necessary changes. In this regard, our study attempted to enable BVSC and other local governments in hazard-prone regions to develop resilient investment planning by identifying the most vulnerable assets and infrastructure, proposing interventions, and exploring the wider set of benefits attributed to selected investments.

From a methodological perspective, we acknowledge that the natural hazard-scenarios were based on historical trends supplemented with expert climate and hazard science knowledge about plausible future trajectories of change. Given the high variation in climate projections for the region, the future impacts over a 35-year horizon are highly uncertain. Our intention, however, was to incentivise participants to consider potential interventions that enhance resilience in their region without compromising their future livelihoods as much as possible. This was also the aim of the two socioeconomic scenarios, which were designed to provoke participants into recommending options that could contribute to high or low population and economic development assumptions in Bega Valley, in consideration of the impending hazard impacts in the future.

In a similar manner, the economic analysis of the costs and benefits of each intervention and bundles of interventions was based on cost-avoidance and benefit-transfer techniques, acknowledging the methodological limitations and low reliability, especially of the latter. We do not claim to have an accurate estimation of the relevant costs and benefits associated with the suggested interventions. However, we consider that in the absence of data, the only option was to use benefit transfer, notwithstanding all of its limitations. Given the significant data limitations we faced, we endeavoured to focus the estimation as much as possible on the relationships between the variables that drive value by exploring the order of economic magnitude of each suggested intervention or bundles of interventions proposed by the participants. The intention was to identify the options that could enable resilient investment on a larger scale, while also using climate and socio-economic scenario analysis to explore the sensitivity of the results to different assumptions about these values and relationships. Similar efforts to evaluate disaster risk reduction options and resilience have also been noted in the literature, acknowledging the significant uncertainty of the outcomes (Jones et al., 2013; Lempert, 2014; Mechler, 2016; Maier et al., 2016; Smith et al., 2017).

5 Conclusion

The development of climate-resilient investment options at a regional and local level requires inclusive and transparent approaches, along with a comprehensive evaluation of the services associated with the proposed solutions. Many potential interventions offer a promising way to address climate hazards while providing multiple co-benefits for people and vital ecosystem services. However, careful planning and implementation are necessary to ensure these solutions achieve their intended goals without creating unintended negative consequences.

In our study, we propose an approach that can enable resilient investment options for natural and built infrastructure to address critical risks and associated hazards aggravated by global environmental changes. As presented in the Bega Valley case study on the southeast coast of Australia, the proposed approach demonstrates the need for integrated hazard analysis with spatial planning coupled with climate projections, economic assessment of

the affected services, and thorough consultation with local authorities and stakeholders to identify resilient investment options.

The underlying assumptions and methodologies of the proposed approach demonstrated in Bega Valley LGA can be further explored and refined if a higher focus on particular domains and sectors (e.g., hazard risk assessment and financial impact assessment) is undertaken. However, we believe that there is an urgency to design more integrated approaches collaboratively developed by the affected communities and the local authorities to enhance preparedness and resilience planning. The insights gained from the case study are anticipated to contribute to the advancement of resilient investment planning in local governments of Australia and regions of other countries encountering similar challenges.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Commonwealth Scientific and Industrial Research Organisation (CSIRO) Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

PB: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review and editing. SX: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review and editing. RW: Conceptualization, Investigation, Methodology, Resources, Validation, Writing – original draft, Writing – review and editing. PH: Conceptualization, Data curation, Formal Analysis, Methodology, Resources, Validation, Writing – original draft, Writing – review and editing. CS: Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft. PP: Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft. SM: Conceptualization, Formal Analysis, Methodology, Validation, Writing – review and editing. GE: Methodology, Validation, Writing – original draft. RG: Conceptualization, Methodology, Writing – review and editing. SA: Data curation, Formal Analysis, Validation, Writing – review and editing. DF: Data curation, Project administration, Resources, Visualization, Writing – review and editing. NM: Conceptualization, Formal Analysis, Methodology, Resources, Visualization, Writing – review and editing. MA: Conceptualization, Investigation, Project administration, Resources, Writing – review and editing. JM: Conceptualization, Funding acquisition, Methodology, Resources, Writing – review and editing. GP: Data curation, Resources, Writing – review and editing. JM: Project administration, Resources, Validation, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships that could potentially create a conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2025.1504043/full#supplementary-material

References

Abad, P., Benito, S., and López, C. (2014). A comprehensive review of value at risk methodologies. *Span. Rev. Financial Econ.* 12 (1), 15–32. doi:10.1016/j.srfe.2013.06.001

ABC News (2020). Indigenous fire management set to scale up in Bega Valley after devastating Black Summer Bushfires. Available online at: https://www.abc.net.au/news/2020-11-12/cultural-burning-set-to-scale-up-in-bega-valley/12871810 (Accessed April 8, 2025).

Adapt NSW (2024). Building better seawalls for biodiversity. Available online at: https://www.climatechange.environment.nsw.gov.au/stories-and-case-studies/living-seawalls (Accessed September 15, 2024).

Ahmed, I., and Ledger, K. (2023). Lessons from the 2019/2020 'Black Summer Bushfires' in Australia. *Int. J. Disaster Risk Reduct.* 96, 103947. doi:10.1016/j.ijdrr.2023.103947

AIDR (2024). Australian disaster resilience knowledge hub- AIDR. Available online at: https://knowledge.aidr.org.au/https://www.nema.gov.au/(Accessed September 25, 2024).

Aldunce, P., Beilin, R., Handmer, J., and Howden, M. (2014). Framing disaster resilience: the implications of the diverse conceptualisations of bouncing back. *Disaster Prev. Manag.* 23 (3), 252–270. doi:10.1108/dpm-07-2013-0130

Alexander, D. E. (2013). Resilience and disaster risk reduction: an etymological journey. *bNat. Hazards Earth Syst. Sci.* 13 (11), 2707–2716. doi:10.5194/nhess-13-2707-2013

Anagnostopoulos, K., Giannopoulou, M., and Roukounis, Y. (2003). Multicriteria evaluation of transportation infrastructure projects: an application of PROMETHEE and GAIA methods. *Adv. Transp.* 14, 599–608.

Asian Infrastructure Investment Bank - AIIB (2023). *Nature as infrastructure*. Beijing, China: AIIB Headquarters.

Austin, J. E., and Seitanidi, M. M. (2012). Collaborative value creation. *Nonprofit Voluntary Sect. Q.* 41, 726–758. doi:10.1177/0899764012450777

Barrett, S., and Chaitanya, R. S. (2023). Getting private investment in adaptation to work: effective adaptation, value, and cash flows. *Glob. Environ. Change* 83, 102761. doi:10.1016/j.gloenvcha.2023.102761

Basak, S., and Shapiro, A. (2001). Value-at-Risk-Based risk management: optimal policies and asset prices. *Rev. Financial Stud.* 14 (2), 371–405. doi:10.1093/rfs/14.2.371

Bega Valley Shire Council (2023). Investment Prospectus. Available online at: https://begavalley.nsw.gov.au/business/investment-prospectus (Accessed September 12, 2023).

Bega Valley Shire Council- BVSC (2020). Residential land strategy. Available online at: https://begavalley.nsw.gov.au/files/Residential-Land-Strategy-2040-Adopted.pdf?v=1595411667 (Accessed September 12, 2023).

Bega Valley Shire Council. – BVSC (2021). Climate resilience strategy 2050. Available online at: https://begavalley.nsw.gov.au/services/climate-resilience-strategy (Accessed September 12, 2023).

Bega Valley Shire Council- BVSC (2022a). Burning off in open areas. Available online at: https:/begavalley.nsw.gov.au/files/Have-Your-Say-Draft-Burning-off-Open-Areas-Policy-screen.pdf?v=1588168166 (Accessed April 4, 2025)

Bega Valley Shire Council- BVSC (2022b). Delivery program 2022 and operational plan 2023–2024. Available online at: https://begavalley.nsw.gov.au/council/delivery-program-and-operational-plan (Accessed September 12, 2023).

Bega Valley Shire Council - BVSC (2023b). Community strategic plan 2042. Available online at: https://begavalley.nsw.gov.au/page.asp?f=RES-WJM-37-21-83 (Accessed September 3, 2023).

Bega Valley Shire Council- BVSVC (2023a). Resourcing strategy 2022-25. Available online at: https://begavalley.nsw.gov.au/council/resourcing-strategy (Accessed September 3, 2023).

Brierley, G. J., and Fryirs, K. (2000). River styles, a geomorphic approach to catchment characterization: implications for river rehabilitation in Bega catchment, New South Wales, Australia. *Environ. Manag.* 25 (6), 661–679. doi:10.1007/s002670010052

Brozović, D., and Tregua, M. (2019). Value creation and sustainability: lessons from leading sustainability firms. *Sustainability* 12 (11), 4450. doi:10.3390/su12114450

Bryan, B. A., Nolan, M., McKellar, L., Connor, J. D., Newth, D., Harwood, T., et al. (2016). Land-use and sustainability under intersecting global change and domestic policy scenarios: trajectories for Australia to 2050. *Glob. Environ. Change* 38, 130–152. doi:10.1016/j.gloenvcha.2016.03.002

Buchtmann, M., Wise, R., O'Connell, D., Crosweller, M., and Edwards, J. (2023). Reforming Australia's approach to hazards and disaster risk: national leadership, systems thinking, and inclusive conversations about vulnerability. *Disaster Prev. Manag.* 32 (1), 49–73. doi:10.1108/DPM-08-2022-0168

Bureau of Meteorology (BOM), Government of Australia (2024). Evapotranspiration calculations: Bega - September 2024 daily calculations. Available online at: http://www.bom.gov.au/watl/eto/tables/nsw/bega/bega.shtml (Accessed September 25, 2024).

Butler, J., Wise, R., Meharg, S., Peterson, N., Bohensky, E., Lipsett-Moore, G., et al. (2022). Walking along with development': climate resilient pathways for political resource curses. *Environ. Sci. Policy* 128, 228–241. doi:10.1016/j.envsci.2021.11.020

Butler, J. R. A., Wise, R. M., Skewes, T. D., Bohensky, E. L., Peterson, N., Suadnya, W., et al. (2015). Integrating top-down and bottom-up adaptation planning to build adaptive capacity: a structured learning approach. *Coast. Manag.* 43 (4), 346–364. doi:10.1080/08920753.2015.1046802

Carr, E. R., and Nalau, J. (2022). Adaptation rationales and benefits: a foundation for understanding adaptation impact. *Clim. Risk Manag.* 39, 100479. doi:10.1016/j.crm.2023.100479

Chaudhary, M. T., and Piracha, A. (2021). Natural disasters—origins, impacts, management. *Encyclopedia* 1 (4), 1101–1131. doi:10.3390/encyclopedia1040084

Christopher, N., Vachette, A., Horne, A., and Kosovac, A. (2024). Enhancing river floodplain management with nature-based solutions: overcoming barriers and harnessing enablers. *Wiley Interdiscip. Rev. Water* 11 (4), e1723. doi:10.1002/wat2.1723

Colloff, M. J., Gorddard, R., Abel, N., Locatelli, B., Wyborn, C., Butler, J. R., et al. (2021). Adapting transformation and transforming adaptation to climate change using a pathways approach. *Environ. Sci. Policy* 124, 163–174. doi:10.1016/j.envsci.2021.06.0144

Colloff, M. J., Lavorel, S., Wise, R. M., Dunlop, M., Overton, I. C., and Williams, K. J. (2016). Adaptation services of floodplains and wetlands under transformational climate change. *Ecol. Appl.* 26 (4), 1003–1017. doi:10.1890/15-0848

Colloff, M. J., Martín-López, B., Lavorel, S., Locatelli, B., Gorddard, R., Longaretti, P., et al. (2017). An integrative research framework for enabling transformative adaptation. *Environ. Sci. Policy* 68, 87–96. doi:10.1016/j.envsci.2016.11.007

Colloff, M. J., Wise, R. M., Palomo, I., Lavorel, S., and Pascual, U. (2020). Nature's contribution to adaptation: insights from examples of the transformation of social-ecological systems. *Ecosyst. People* 16 (1), 137–150. doi:10.1080/26395916.2020.1754919

Colombo, M. G., Hoisl, K., Reichstein, T., and Torrisi, S. (2023). Open innovation, value creation and value capture: an introduction. *J. Ind. Bus. Econ.* 50, 731–742. doi:10.1007/s40812-023-00285-x

Cook, B. R. (2024). Flood risk management of the future: a warning from a land down under. *J. Flood Risk Manag.* 17 (1), e12985. doi:10.1111/jfr3.12985

CSIRO (2024). Drought resilience. Available online at: https://www.csiro.au/en/about/challenges-missions/Drought-Resilience (Accessed May 12, 2024).

DAFF (2025). Department of agriculture, fisheries and forestry (DAFF). Australian Government. Available online at: https://www.agriculture.gov.au/agriculture-land/farm-food-drought/drought/future-drought-fund/next-phase (Accessed January 12, 2025).

Dagdeviren, M. (2008). Decision making in equipment selection: an integrated approach with AHP and PROMETHEE. *J. Intell. Manuf.* 19, 397–406. doi:10.1007/s10845-008-0091-7

Debele, S. E., Leo, L. S., Kumar, P., Sahani, J., Ommer, J., Bucchignani, E., et al. (2023). Nature-based solutions can help reduce the impact of natural hazards: a global analysis of NBS case studies. *Sci. Total Environ.* 902, 165824. doi:10.1016/j.scitotenv.2023.165824

Deloitte Access Economics (2021). Special report: update to the economic costs of natural disasters in Australia. Available online at: https://www.deloitte.com/au/en/services/economics/perspectives/building-australias-natural-disaster-resilience.html (Accessed September 25, 2024).

Department of Climate Change, Energy, the Environment and Water (CEEW), Government of Australia (2023). National climate risk assessment methodology. Available online at: https://www.dcceew.gov.au/climate-change/publications/national-climate-risk-assessment (Accessed September 25, 2024).

Department of Climate Change, Energy, the Environment and Water (CEEW), Government of Australia (2024). Nature-based solutions for climate. Available online at: https://www.dcceew.gov.au/climate-change/policy/nature-based-solutions-for-climate (Accessed September 25, 2024).

Department of Foreign Affairs and Trade, Australian- DFAT Government (2024). Investing in nature-based solutions. Available online at: https://www.dfat.gov.au/international-relations/themes/climate-change/supporting-indo-pacific-tackle-climate-change/investing-nature-based-solutions (Accessed September 25, 2024).

Dickman, C. R. (2021). Ecological consequences of Australia's "Black Summer" bushfires: managing for recovery. *Integr. Environ. Assess. Manag.* 17, 1162–1167. doi:10.1002/ieam.4496

Evmenchik, O. S., Niyazbekova, S. U., Seidakhmetova, F. S., and Mezentceva, T. M. (2021). "The role of gross profit and margin contribution in decision making," in *Socio-economic systems: paradigms for the future. Studies in systems, decision and control*. Editors E. G. Popkova, V. N. Ostrovskaya, and A. V. Bogoviz (Cham: Springer), 314, 1393–1404. doi:10.1007/978-3-030-56433-9_145

Frantzeskaki, N., McPhearson, T., Collier, M. J., Kendal, D., Bulkeley, H., Dumitru, A., et al. (2019). Nature-based solutions for urban climate change adaptation: linking science, policy, and practice communities for evidence-based decision-making. *BioScience* 69 (6), 455–466. doi:10.1093/biosci/biz042

Gallina, V., Torresan, S., Critto, A., Sperotto, A., Glade, T., and Marcomini, A. (2016). A review of multi-risk methodologies for natural hazards: consequences and challenges

for a climate change impact assessment. *J. Environ. Manag.* 168, 123–132. doi:10.1016/j.jenvman.2015.11.011

Gorddard, R., Colloff, M. J., Wise, R. M., Ware, D., and Dunlop, M. (2016). Values, rules and knowledge: adaptation as change in the decision context. *Environ. Sci. Policy* 57, 60–69. doi:10.1016/j.envsci.2015.12.004

Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Bangalore, M., and Beaudet, C. (2020). From poverty to disaster and back: a review of the literature. *EconDisCliCha* 4, 223–247. doi:10.1007/s41885-020-00060-5

Hazrds CRC (2024). Value tool for natural hazards. Available online at: https://tools.bnhcrc.com.au/wtp/tool/start (Accessed January 12, 2023).

Infrastructure Victoria (2016). Value capture – options, challenges and opportunities for Victoria policy paper. Available online at: https://www.infrastructurevictoria.com.au/resources/value-capture (Accessed January 12, 2024).

International Monetary Fund- IMF, Western Hemisphere Dept (2024). Economic benefits of building resilience to natural hazards and climate change. *IMF Staff Coun. Rep.* 2024 (134), *A002*. doi:10.5089/9798400276729.002.A002

Ishiwatari, M., and Surjan, A. (2019). Good enough today is not enough tomorrow: challenges of increasing investments in disaster risk reduction and climate change adaptation. *Prog. Disaster Sci.* 1, *100007*. doi:10.1016/j.pdisas.2019.100007

Jones, R. L., and Tubeuf, S. (2022). Human and economic impacts of natural disasters: can we trust the global data? *Sci. Data* 9 (1), 1–7. doi:10.1038/s41597-022-01667-x

Jones, R. N., Young, C. K., Handmer, J., Keating, A., Mekala, G. D., and Sheehan, P. (2013). *Valuing adaptation under rapid change, national climate change adaptation research facility*. Gold Coast, 184. Available online at: https://nccarf.edu.au/wp-content/uploads/2019/03/Jones_2013_Valuing_adaptation_under_rapid_change.pdf (Accessed January 10, 2025).

Kemter, M., Fischer, M., Luna, L. V., Schönfeldt, E., Vogel, J., Banerjee, A., et al. (2021). Cascading hazards in the aftermath of Australia's 2019/2020 Black Summer wildfires. *Earth's Future* 9 (3), e2020EF001884. doi:10.1029/2020EF001884

Kernaghan, S., and Sturgeon, A. (2024). Valuing nature as Urban health infrastructure: a pathway to a nature positive city. Oxford, *Open Infrastructure and Health*, 2. doi:10.1093/ooih/ouae007

Knezic, S., and Mladineo, N. (2006). GIS-based DSS for priority setting in humanitarian mine-action. *Int. J. Geogr. Inf. Sci.* 20 (5), 565–588. doi:10.1080/13658810600607303

Lempert, R. J. (2014). Embedding (some) benefit-cost concepts into decision support processes with deep uncertainty. *J. Benefit Cost Anal.* 5 (3), 487–514. doi:10.1515/jbca-2014-9006

Li, Y., Li, A., and Liu, Z. (2017). Two ways of calculating VaR in risk management:an empirical study based on CSI 300 index. *Proc. Comput. Sci.* 139, 432–439. doi:10.1016/j.procs.2018.10.259

Lim, M., and Xenarios, S. (2021). Economic assessment of urban space and blue-green infrastructure in Singapore. *J. Urban Ecol.* 7 (1). doi:10.1093/jue/juab020

Lin, B. B., Capon, T., Langston, A., Taylor, B., Wise, R., Williams, R., et al. (2017). Adaptation pathways in coastal case studies: lessons learned and future directions. *Coast. Manag.* 45 (5), 384–405. doi:10.1080/08920753.2017.1349564

Macharis, C., Brans, J. P., and Mareschal, B. (1998). The GDSS PROMETHEE procedure – a PROMETHEE–GAIA based procedure for group decision support. *J. Decis. Syst.* 7, 283–307.

Maier, H., Guillaume, J., Van Delden, H., Riddell, G., Haasnoot, M., and Kwakkel, J. (2016). An uncertain future, deep uncertainty, scenarios, robustness and adaptation: how do they fit together? *Environ. Model. Softw.* 81, 154–164. doi:10.1016/j.envsoft.2016.03.014

Malczewski, J. (1999). "Spatial multicriteria decision analysis," in *Spatial multicriteria decision making and analysis - a geographic information sciences approach*. Editor J. C. Thill (New York, N.Y: Ashgate), 11–48.

Manandhar, S., Xenarios, S., Schmidt-Vogt, D., Hergarten, C., and Foggin, M. (2018). *Climate vulnerability and adaptive capacity of mountain societies in central asia*. University of Central Asia.

Mareschal, B., and Brans, J. P. (1988). Geometrical representations for MCDA. *Eur. J. Operat.Res.* 34, 69–77. doi:10.1016/0377-2217(88)90456-0

Marinoni, O. (2005). A stochastic spatial decision support system based on PROMETHEE. *Int. J. Geogr. Inf. Sci.* 19, 51–68. doi:10.1080/13658810412331280176

Maru, Y. T., Stafford Smith, M., Sparrow, A., Pinho, P. F., and Dube, O. P. (2014). A linked vulnerability and resilience framework for adaptation pathways in remote, disadvantaged communities. *Glob. Environ. Change* 28, 337–350. doi:10.1016/j.gloenvcha.2013.12.007

Mechler, R. (2016). Reviewing estimates of the economic efficiency of disaster risk management: opportunities and limitations of using risk-based cost–benefit analysis. *Nat. Hazards* 81, 2121–2147. doi:10.1007/s11069-016-2170-y

Meharg, S. (2023a). Critical change agent characteristics and competencies for ensuring systemic climate adaptation interventions. *Sustain Sci.* 18, 1445–1457. doi:10.1007/s11625-022-01250-8

Meharg, S. (2023b). "Enhancing research for development," in *Catalysing change agents* (Cham: Springer). doi:10.1007/978-3-031-36433-4_10

Morris, R. L., Campbell-Hooper, E., Waters, E., Bishop, M. J., Lovelock, C. E., Lowe, R. J., et al. (2024b). Current extent and future opportunities for living shorelines in Australia. *Sci. Total Environ.* 917, 170363. doi:10.1016/j.scitotenv.2024.170363

Morris, R. L., Pomeroy, A. W., Boxshall, A., Colleter, G., Dack, D., Dunlop, A. R., et al. (2024a). A blueprint for overcoming barriers to the use of nature-based coastal protection in Australia. *Front. Environ. Sci.* 12, 1435833. doi:10.3389/fenvs.2024.1435833

Morris, R. L., Strain, E. M. A., Konlechner, T. M., Fest, B. J., Kennedy, D. M., Arndt, S. K., et al. (2019). Developing a nature-based coastal defence strategy for Australia. *Aust. J. Civ. Eng.* 17 (2), 167–176. doi:10.1080/14488353.2019.1661062

Mortimer, G. W. B., and Lee, C. (2020). Adaptation finance: emerging approaches to solve the climate adaptation finance gap. Australia: Climate-KIC. Available online at: https://www.climate-kic.org.au/our-projects/adaptation-finance2020 (Accessed January 12, 2025).

Nariswari, T. N., and Nugraha, N. M. (2020). Profit growth: impact of net profit margin, gross profit margin and total assests turnover. *Int. J. Finance and Bank. Stud. (2147–4486)* 9 (4), 87–96. doi:10.20525/ijfbs.v9i4.937

Nasiri, H., Darvishi Boloorani, A., Faraji Sabokbar, H. A., Jafari, H. R., Hamzh, M., and Rafii, Y. (2013). Determining the most suitable areas for artificial groundwater recharge via an integrated PROMETHEE II-AHP method in GIS environment (case study: Garabaygan Basin, Iran). *Environ. Monit. Assess.* 185 (1), 707–718. doi:10.1007/s10661-012-2586-0

NEEMA (2024a). National emergency management agency (NEEMA). Available online at: https://www.nema.gov.au/ (Accessed September 25, 2024).

NEEMA (2024b). National emergency management agency (NEEMA). Available online at: https://www.nema.gov.au/our-work/disaster-recovery/disaster-recovery-funding-arrangements (Accessed September 25, 2024).

NEEMA (2024c). National emergency management agency (NEEMA). Available online at: https://www.nema.gov.au/about-us/governance-and-reporting/strategies-and-frameworks/disaster-risk-reduction (Accessed September 26, 2024).

NEEMA (2024d). National emergency management agency (NEEMA). Available online at: https://www.nema.gov.au/our-work/resilience/hazards-insurance-partnership (Accessed September 27, 2024).

New South Wales -NSW (2022). NSW climate change adaptation strategy. Available online at: https://www.climatechange.environment.nsw.gov.au/home (Accessed September 25, 2023).

New South Wales- NSW (2023). Plausible divergent futures. Available online at: https://www.climatechange.environment.nsw.gov.au/sites/default/files/2022-11/Sarah-Tasic-The-power-of-future-climate-scenarios.pdf (Accessed September 25, 2023).

Newth, D., Gooley, G., and Gunasekera, D. (2021). Socio-economic analysis of climate services in disaster risk reduction: a perspective on Pacific SIDS. *Front. Environ. Sci.* 9, 681747. doi:10.3389/fenvs.2021.681747

NSW Department of Planning and Environment (2022). *Draft South East and tablelands regional plan 2041*. Sydney, Australia: NSW.

O'Connell, D., Maru, Y., Grigg, N., Walker, B., Abel, N., Wise, R., et al. (2019). "Resilience, adaptation pathways and transformation approach," in *A guide for designing, implementing and assessing interventions for sustainable futures (version 2)*. Australia: CSIRO.

O'Connell, D., Wise, R., Doerr, V., Grigg, N., Williams, R., Meharg, S., et al. (2018). *Approach, methods and results for co-producing a systems understanding of disaster. Technical Report Supporting the Development of the Australian Vulnerability Profile*. Australia: CSIRO.

Okuda, K., and Kawasaki, A. (2022). Effects of disaster risk reduction on socio-economic development and poverty reduction. *Int. J. Disaster Risk Reduct.* 80, 103241. doi:10.1016/j.ijdrr.2022.103241

Omukuti, J. (2024). The need for a climate-resilient development-aligned framing of innovative climate finance. *Curr. Opin. Environ. Sustain.* 66, 101400. doi:10.1016/j.cosust.2023.101400

O'Neill, B. C., Carter, T. R., Ebi, K., Harrison, P. A., Kemp-Benedict, E., Kok, K., et al. (2020). Achievements and needs for the climate change scenario framework. *Nat. Clim. Chang.* 10, 1074–1084. doi:10.1038/s41558-020-00952-0

Patel, S., Soanes, M., Rahman, M., Smith, B., Steinbach, D., and Barrett, S. (2020). *Good climate finance guide: lessons for strengthening devolved climate finance*. London: IIED.

Prvulovic, S., Tolmac, D., and Radovanovic, L. (2011). Application of PROMETHEE-gaia methodology in the choice of systems for drying paltry- seeds and powder materials. *Strojniski vestnik - J. Mech. Eng.* 57 (10), 778–784. doi:10.5545/sv-jme.2008.068

PwC (2017). Investing in the future: using value creation and value capture to fund the infrastructure our cities need. Available online at: https://www.pwc.com.au/infrastructure/investing-future-value-capture-jan17.pdf (Accessed November 20, 2023).

Raikes, J., Smith, T. F., Baldwin, C., and Henstra, D. (2020). Linking disaster risk reduction and human development. *Clim. Risk Manag.* 32, 100291. doi:10.1016/j.crm.2021.100291

Richards, S. J. (2021). A value-at-risk approach to mis-estimation risk. *Br. Actuar. J.* 26, e13. doi:10.1017/S1357321721000131

Russell-Smith, J., McCaw, L., and Leavesley, A. (2020). Adaptive prescribed burning in Australia for the early 21st Century – context, status, challenges. *Int. J. Wildland Fire* 29, 305–313. doi:10.1071/wf20027

Sangha, K. K., Ahammad, R., Russell-Smith, J., and Costanza, R. (2024). Payments for ecosystem services opportunities for emerging nature-based solutions: integrating indigenous perspectives from Australia. *Ecosyst. Serv.* 66, 101600. doi:10.1016/j.ecoser.2024.101600

Schrödl, H., and Turowski, K. (2014). Risk management in hybrid value creation. *Decis. Support Syst.* 58, 21–30. doi:10.1016/j.dss.2012.12.042

Smith, N., Brown, C., McDonald, G., Ayers, M., Kipp, R., and Saunders, W. (2017). Challenges and opportunities for economic evaluation of disaster risk decisions. *EconDisCliCha* 1, 111–120. doi:10.1007/s41885-017-0007-0

Smith, W., Neale, T., and Weir, J. K. (2021). Persuasion without policies: the work of reviving Indigenous peoples' fire management in southern Australia. *Geoforum* 120, 82–92. doi:10.1016/j.geoforum.2021.01.015

Sparkes, E., Cotti, D., Shekhar, H., Werners, S. E., Valdiviezo-Ajila, A. A., Banerjee, S., et al. (2023). Impact webs: a novel approach for characterising and assessing multi-risk in complex systems. *EGU General Assem.* 2023, EGU23-3461. doi:10.5194/egusphere-egu23-3461

Stafford-Smith, M., Rissik, D., Street, R., Lin, B., Doerr, V., Webb, R., et al. (2022). Climate change adaptation guidance: clarifying three modes of planning and implementation. *Clim. Risk Manag.* 35, 100392. doi:10.1016/j.crm.2021.100392

Sung, C. H., and Liaw, S. C. (2021). Using spatial pattern analysis to explore the relationship between vulnerability and resilience to natural hazards. *Int. J. Environ. Res. Public Health* 18 (11), 5634. doi:10.3390/ijerph18115634

Szetey, K., Moallemi, E. A., Ashton, E., Butcher, M., Sprunt, B., and Bryan, B. A. (2021). Co-creating local socioeconomic pathways for achieving the sustainable development goals. *Sustain Sci.* 16, 1251–1268. doi:10.1007/s11625-021-00921-2

Tailwind (2024). Taxonomy for climate adaptation and resilience activities. Available online at: https://www.tailwindclimate.com/wp-content/uploads/2024/05/Taxonomy-Companion-Deck-May-2024-FINAL.pdf (Accessed November 20, 2023).

Tasri, E. S., Karimi, K., and Muslim, I. (2021). The effect of economic variables on natural disasters and the impact of disasters on economic variables. *Heliyon* 8 (1), e08678. doi:10.1016/j.heliyon.2021.e08678

Transport for NSW (TfNSW) (2023). Travel zone projections 2022. Available online at: https://www.transport.nsw.gov.au/(Accessed November 20, 2023).

United Nations Office for Disaster Risk Reduction (UNDRR) (2017). The Sendai framework terminology on disaster risk reduction "Resilience". Available online at: https://www.undrr.org/terminology/resilience (Accessed March 8, 2025).

Urbanista (2019). Growth scenarios for Bega Valley Shire profile areas. Available online at: https://begavalley.nsw.gov.au/files/Urbanista-Bega-Valley-Growth-Scenarios.pdf?v=1586774679 (Accessed November 20, 2023).

Victorian Government, Department of Environment, Land, Water and Planning (2020). Place-based adaptation concepts and approaches. Available online at: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0037/489682/RAS-GN1_Place-based-adaptation-concepts-and-approaches.pdf (Accessed September 20, 2024).

Victorian Government Value (2021). Creation and capture framework. Available online at: https://www.vic.gov.au/value-creation-and-capture-framework (Accessed September 20, 2024).

Walker, B., Crépin, A., Nyström, M., Anderies, J. M., Andersson, E., Elmqvist, T., et al. (2023). Response diversity as a sustainability strategy. *Nat. Sustain.* 6 (6), 621–629. doi:10.1038/s41893-022-01048-7

Walker, B. H. (2020). Resilience: what it is and is not. *Ecol. Soc.* 25 (2), art11. doi:10.5751/es-11647-250211

Wang, S., Zhang, M., Huang, X., Hu, T., Sun, Q. C., Corcoran, J., et al. (2022). Urban–rural disparity of social vulnerability to natural hazards in Australia. *Sci. Rep.* 12 (1), 13665–13715. doi:10.1038/s41598-022-17878-6

Ward, P. J., Blauhut, V., Bloemendaal, N., Daniell, J. E., de Ruiter, M. C., Duncan, M. J., et al. (2020). Review article: natural hazard risk assessments at the global scale. *Nat. Hazards Earth Syst. Sci.* 20, 1069–1096. doi:10.5194/nhess-20-1069-2020

Werners, S. E., Wise, R. M., Butler, J. R., Totin, E., and Vincent, K. (2021). Adaptation pathways: a review of approaches and a learning framework. *Environ. Sci. Policy* 116, 266–275. doi:10.1016/j.envsci.2020.11.003

Wise, R., Fazey, I., Stafford Smith, M., Park, S., Eakin, H., Archer Van Garderen, E., et al. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. *Glob. Environ. Change* 28, 325–336. doi:10.1016/j.gloenvcha.2013.12.002in

Wise, R., Marinopoulos, J., O'Connell, D., Mesic, N., Tieman, G., Gorddard, R., et al. (2022b). Guidance for applying the enabling resilience investment framework: building national capability for enabling resilience investment. 2022. EP2022-5037. doi:10.25919/vkh4-mh60

Wise, R. M., Box, P., Tasic, S., Meharg, S., Collins, P., Heinmiller, P., et al. (2024). "Strategically responding to climate hazards in the Illawarra Shoalhaven region, Australia. Demonstrating a multi-hazard disaster opportunity and risk assessment methodology and regional adaptation pathways planning approach in strategic land-use planning," in *Report prepared for the NSW department of planning, housing and infrastructure*. Australia: CSIRO Environment.

Wise, R. M., Capon, T., Lin, B. B., and Stafford-Smith, M. (2022a). Pragmatic cost–benefit analysis for infrastructure resilience. *Nat. Clim. Chang.* 12, 881–883. doi:10.1038/s41558-022-01468-5

World Bank Group (2021). *Resilience rating system: a methodology for building and tracking resilience to climate change*. Washington, DC: World Bank. Available online at: http://hdl.handle.net/10986/35039.

XDI (2024). XDI gross domestic climate risk. Available online at: https://archive.xdi.systems/xdi-benchmark-gdcr/(Accessed November 20, 2023).

Xenarios, S., and Polatidis, H. (2015). Alleviating climate change impacts in rural Bangladesh: a PROMETHEE outranking-based approach for prioritizing agricultural interventions. *Environ. Dev. Sustain* 17, 963–985. doi:10.1007/s10668-014-9583-0

Zhang, Y., Beggs, P. J., McGushin, A., Bambrick, H., Trueck, S., Hanigan, I. C., et al. (2020). The 2020 special report of the MJA–Lancet Countdown on health and climate change: lessons learnt from Australia's "Black Summer". *Med. J. Aust.* 213 (11), 490–492.e10. doi:10.5694/mja2.50869

Zhu, D., Zhang, Y., Kendal, D., Fraser, L., and Flies, E. J. (2023). Nature-based solutions in Australia: a systematic quantitative literature review of terms, application and policy relevance. *Nature-Based Solutions* 4, 100092. doi:10.1016/j.nbsj.2023.100092