PATHWAYS2RESILIENCE

D6.1 –

Decision Framework to Deliver Multiple Resilience Dividends

WP6 – Task 6.1

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Summary

This deliverable presents a decision-making framework centred on the Multiple Resilience Dividends (MRD) concept in the context of Climate Change Adaptation (CCA) within the scope of the Pathways2Resilience (P2R) programme. The MRD concept, grounded in both conceptual and empirical research, evaluates the overall positive impacts (i.e., benefits and co-benefits) and adverse effects (i.e., co-costs and trade-offs) of adaptation interventions, aiming to support decision-making on CCA.

The MRD concept conceives adaptation interventions as multifaceted and with effects across sectors and domains—Key Community Systems (KCS) in the context of the Adaptation Mission. By highlighting opportunities to achieve multiple societal goals while addressing and managing climate-related risks, the MRD concept proposes a cross-cutting developmental approach for building resilience systemically while creating a strong case for CCA investments.

The framework follows an eight-step decision-making cycle for CCA, from identifying problems to monitoring outcomes, and adopts a multisectoral perspective that recognises the interconnectedness, synergies and trade-offs across KCS. The framework is designed for European local and regional authorities and can be adapted to different stakeholders' needs and resilience maturity levels. It is seamlessly integrated into the Regional Resilience Journey (RRJ) and other deliverables developed within P2R, such as methodologies for adaptation pathways (D6.2) and innovation agenda formulation (D6.4). Within the RRJ, the framework has a salient practical value in identifying and assessing options by leveraging various methods and tools (e.g., Cost-Benefit Analysis, Multi-Criteria Analysis, and Robust Decision-Making) to characterise MRD consistent with local capacities and conditions. Ultimately, the framework serves as a powerful enabler for regions seeking to achieve systemic resilience.

In essence, the MRD framework fosters a shift towards transformative CCA decision-making, encouraging adaptation strategies that address vulnerabilities and risks in an integrated manner. It opens new perspectives for regions to envision multiple paths based on the adaptation options they choose—each with unique possibilities and outcomes to consider. By leveraging multi-disciplinary knowledge and focusing on systemic resilience, the framework serves as a catalyst for sustainable, effective, and transformational decisions in CCA.

Keywords

Climate Adaptation

Decision-making

Resilience Dividend

Systemic Resilience

Co-benefits

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Abbreviations and acronyms

Acronym	Description
CBA	Cost-Benefit Analysis
CCA	Climate Change Adaptation
CEA	Cost-Effective Analysis
DRR	Disaster Risk Reduction
KCS	Key Community Systems
MCA	Multi-Criteria Analysis
MRD	Multiple Resilience Dividends
P2R	Pathways to Resilience
RDM	Robust Decision-Making
RRJ	Regional Resilience Journey
TRD	Triple Resilience Dividend
WP	Work Package

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Introduction

In the face of escalating climate change impacts, the urgency for effective CCA strategies is paramount. The European Union's Adaptation Mission (European Commission, 2021a) and Strategy (European Commission, 2021b) aim to create resilient regions capable of addressing future climatic challenges through smarter, swifter, and more systemic adaptation. P2R is one of the central support mechanisms in this endeavour, and it will support up to 100 regions and communities across Europe in creating their resilience pathways. Work Package 6 (*Support Services on Key Community Systems to design climate resilience pathways and innovation agendas*) will support the formulation of pathways through flexible and adaptable processes that build on existing state-of-the-art knowledge, tools, and methods, and will offer technical guidance and toolbox to the regions for the development of transformative climate resilience pathways.

A starting step in WP6 in Task 6.1 is the development of practical frameworks, methodologies, and tools to support regions and communities along the RRJ. The aim of this report, "*Decision Framework to Deliver Multiple Resilience Dividends*", as a part of T6.1, is to discuss and propose how to integrate MRD –the overall net benefits delivered by adaptation—across the adaptation decision-making process. This will then help to build a stronger cross-sectoral and systemic case for adaptation.

By introducing a decision-making framework based on the current state of the art, various case studies, and best practices, this deliverable provides a comprehensive resource for local and regional authorities to deliver MRD across and in different KCS. This deliverable brings together a vast array of literature on the benefits of climate adaptation and related potential adverse effects to propose a conceptual framework explicitly outlining how the integration of dividends-thinking can inform adaptation practice.

This deliverable is structured into five sections. Section 1 describes the decision-making in the CCA context and establishes a need for a practical decision-making framework, addressing its importance and rationale. Section 2 delves into the Resilience Dividend concept, defines Multiple Dividends of Resilience, and offers concrete examples of MRD in various KCS, including a cross-KCS one. Section 3 presents the research approach used in developing this deliverable. Section 4 comprehensively describes the MRD framework and the context for its implementation and provides an overview of methods for characterising MRD in CCA. Finally, Section 5 discusses the implications of the MRD framework for P2R and explores its integration into the RRJ, its interlinkage with other P2R deliverables (e.g., adaptation pathways), and its role in advancing transformational adaptation.

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1 Setting the Scene

In this section, we establish the foundations for the content of the deliverable. It comprises three integral sub-sections: the first provides an overview of the decision-making in the CCA context, the second describes the influence of adaptation-related decisions in supporting conditions for sustainable development, the third advocates for the development of a pragmatic decision-making framework for CCA that recognises the multiple benefits of resilience.

1.1 Decision-making in the Context of Climate Change Adaptation

Decision-making in the context of climate change is defined as "*decisions made by an actor or set of actors (i.e., individual, household, community, organisation, society) that have implications from the perspective of the systems that affect, or are affected by, climate change*" (Orlove *et al.*, 2020, p. 276). This highlights the importance of considering multiple sources of information and evidence to ensure high-quality input that leads to effective decision-making, especially in terms of problem recognition, evaluating adaptation options, and adaptive management of interventions. Thus, decision-making in the CCA context is part of a dynamic, cyclical and iterative process of risk management (New *et al.*, 2022).

A decision-making process typically involves different cognitive phases such as 'problem framing' (which includes understanding goals, threats, and drivers of risk; Tanner *et al.*, 2016, p. 18), followed by 'analysing' and 'exploring' and a 'sense-making phase' (New *et al.*, 2022, p. 2567; Figure 1). According to IPCC's AR6, four enabling conditions[1] for adaptation can influence the decision-making process: *Knowledge and Capacity* (including models and data with future scenario considerations), *Governance* (e.g., legislation, institutions, national/international agreements), *Finance* aspects (e.g., needs or sources), and *Catalysing Conditions* such as cultural, social, political and economic norms or behavioural aspects can influence informal aspects of decision-making (World Bank, 2021; New *et al.*, 2022). Within these enabling conditions and as central to adaptation governance, effective and inclusive decision-making has the potential to comprehensively shape adaptation processes and steer in the direction of innovation and transformative solutions.

Decision-making is an inherently complex task that is often confronted with a multitude of uncertainties. Climate change brings additional complications by significantly amplifying the uncertainty associated with climate-related risks and ways to manage them (Marchau *et al.*, 2019). As a result, decision-makers face considerable difficulties in identifying, assessing, and predicting the outcomes of adaptation options. This further emphasises the need for decision-making frameworks that can effectively cope with the increased level of uncertainty (e.g. future climate projections, complexity of climatic systems, socio-economic development trajectories, cross-sectoral and transboundary risks, indirect impacts and cascading effects) and provide reliable guidance for decision-makers.

Decision-making in CCA is a time-sensitive matter: seizing windows of opportunity can greatly impact the ability to adapt and enact meaningful transformations. During such moments, steps can be accelerated or ignored, potentially leading to impetuous, and, ultimately, unsustainable

[1] In the context of the EU Mission Adaptation (Directorate-General for Climate Action, 2023), the P2R programme refers to seven Key Enabling Conditions (KEC) formulated as: "*Knowledge and data*", "*Governance, engagement and collaboration*", "*Finances and resources*", "*Capabilities and Skills*", "*Behavioural Change*", and "*Experiment, learn & reflect*".

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decisions—situations that must be avoided. By anticipating and preparing for these opportunities with better information, decision-makers can facilitate a sustainable adaptation process through a more holistic strategy that accounts for both short- and long-term benefits.

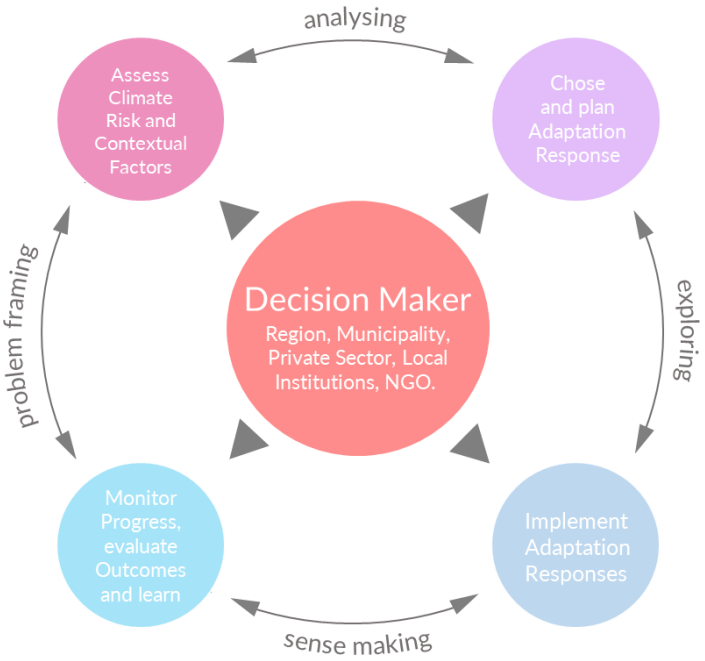

Figure 1. Simplified steps that a decision maker faces in managing climate change risks (Adapted from New et al. 2022, p. 2549).

However, the urgency to reshape the decision-making approach in CCA becomes evident when confronting the adaptation gap[2]. Although there has been some progress in recent years, current investments in CCA remain inadequate due to various factors (*see* Box 1*)*. These include but are not limited to, the tendency to perceive these investments as 'sunk' costs, constrained public and private budgets for climate-related issues, limited understanding of climate risks, the ready availability of international post-disaster aids or the prioritisation of short-term gains over long-term benefits by politicians and citizens (Tanner and Rentschler, 2015; Mechler and Hochrainer-Stigler, 2019; World Bank, 2021; UNDRR, 2022; United Nations Environment Programme, 2022; Doeffinger and Rubinyi, 2023; Rözer *et al.*, 2023). According to the Intergovernmental Panel on Climate Change (IPCC), CCA is "*fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near term risks, and focused more on planning rather than implementation*" (IPCC, 2022, p. 50). Moreover, the overall funding allocated for building climate resilience, particularly the financing flow towards adaptation, has been slowing down lately (United Nations Environment Programme, 2023), strengthening the case for the shift in decision-making (Helgeson and O'Fallon, 2021; Rözer *et al.*, 2023).

[2] According to UNEP in its Adaptation Gap Report 2023, the gap in financing for adaptation is increasing and currently ranges between US$194 billion and US$366 billion annually, requiring funding 10 to 18 times greater than the current international public adaptation funding - at least 50% higher than previously estimated (United Nations Environment Programme, 2023)

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Factors hindering progress on adaptation.

Informational gaps
- Low awareness of climate change.
- Limited access to data and information to support adaptation planning.
- Lack of appropriate data and tools to monitor and evaluate adaptation.
- No consideration of adaptation interlinkages with other climate actions and sustainability efforts.

Institutional barriers
- Lack of coordination between agencies and government levels.
- Absence of adaptation priorities in plans and policies.
- Inadequate programming capacity.

Technical shortfalls
- Policies and projects tend to be oriented towards the short term and focused on single hazards.
- Interventions inadequately address the root causes of climate exposure and vulnerability.
- Adaptation responses insufficiently address the compounding and cascading nature of climate risk.
- Policies and projects implemented at an inappropriate scale.

Financial barriers
- Inadequacy of financial resources.
- Limited understanding of and access to available financing mechanisms.
- Unavailability of public funds.
- Low grant-to-loan ratios.
- Co-financing requirements.
- Rigid rules of climate funds.

External non-climate factors
- The war in Ukraine.
- COVID-19 emergency and recovery.
- Rapid intensification of climate extreme events.
- Other disasters.

Extracted from the Adaptation Gap Report 2022 (United Nations Environment Programme, 2022) *and* the Adaptation Report 2023 (United Nations Environment Programme, 2023).

Box 1. Factors hindering progress on adaptation.

1.2 The Role of Adaptation-related Decisions in Supporting Sustainable Development Conditions

The consequences of not investing in building climate resilience can lead to missed opportunities, resulting in losses even in the absence of climate-related disasters (Tanner and Rentschler, 2015). The presence of climate risks deters investments in productive capital and innovation, which hinders long-term planning and economic growth prospects (Tanner and Rentschler, 2015; Doeffinger and Rubinyi, 2023). Therefore, decision-making in CCA needs to be reconceived to identify adaptation responses that maximise development opportunities and sustainability efforts while minimising and managing climate risks (Tanner and Rentschler, 2015; Helgeson and O'Fallon, 2021).

By seeing development through a risk-aware lens, climate adaptation can catalyse poverty reduction (Tanner and Rentschler, 2015; Mechler and Hochrainer-Stigler, 2019). In various regions, climate-induced costs not only encompass damages and losses on lives, assets, livelihoods, education, and health (Heubaum *et al.*, 2022) but also disasters disrupt economic

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development, exacerbate poverty, and escalate government debt (Rözer *et al.*, 2023). The escalating climate-related disasters drive economic and humanitarian losses, disproportionately affecting urban areas (Doeffinger and Rubinyi, 2023). Data reveals this urgency: Europe experienced extreme weather events in 2022, which resulted in economic losses of more than $38.8 billion in which the windstorm series (Dudley, Eunice, and Franklin) caused $6.2 billion of economic losses, and severe droughts and heatwaves in Southern, Central and Western Europe caused $22 billion of agricultural economic losses (AON, 2023). *Business-as-usual* projections for 2050 predict a temperature rise of 2–2.6°C, which may result in an 11–14% reduction in the global economic output (Guo, Kubli and Saner, 2021). In line with that, the IPCC emphasises the importance of integrating climate mitigation and adaptation into societal transitions and systems transformation to pursue climate-resilient development pathways and achieve poverty eradication and inequalities (IPCC, 2018). Without prompt action and the necessary increase in climate adaptation, the convergence of socio-economic trends and climate change can worsen losses and damages in the future (IPCC, 2018; Bouwer, 2019; Formetta and Feyen, 2019). Hence, it is clear that climate adaptation and resilience-building should be integrated into sustainable development endeavours, strengthening the case for the shift in decision-making (Helgeson and O'Fallon, 2021; Rözer *et al.*, 2023).

Developing a strong business case for CCA is an effective approach to promoting climate-resilient development and building sustainable societies. Doing so can foster sustainable urban development and shared regional prosperity (Fung *et al.*, 2021; Heubaum *et al.*, 2022; Doeffinger and Rubinyi, 2023). Rotterdam, for example, uses its climate resilience achievements to attract investors and a dynamic workforce, fostering economic and social growth (Tanner and Rentschler, 2015). These types of resilience investments demand that different actors involved across the decision-making stages recognise the wider array of benefits of climate adaptation. Recognising the full potential of building climate resilience challenges the traditional focus on avoiding losses and positions adaptation as a lever for broader development objectives (Doeffinger and Rubinyi, 2023), a catalyst for growth and shared prosperity (Tanner and Rentschler, 2015). Under this analytical approach, building climate resilience and societal development is only a matter of perspective (Doeffinger and Rubinyi, 2023).

1.3 Integrating the Multiple Benefits of Resilience to Enhance Adaptation-related Decisions

Evaluating adaptation options without accounting for the wide range of their benefits is an incomplete assessment (Doeffinger and Rubinyi, 2023). Traditionally, in CCA projects, evaluation methods have been used to quantify loss avoidance benefits without considering the full spectrum of benefits (Tanner and Rentschler, 2015; Mechler and Hochrainer-Stigler, 2019; Doeffinger and Rubinyi, 2023). Given that these conventional approaches for appraising options fall short of fully encompassing adaptation benefits, it gives the idea that investing in climate resilience is unnecessary without an imminent disaster event such as a high-return-period storm or a large wildfire (Keefe, 2018; Helgeson and O'Fallon, 2021). Moreover, since additional economic, social, and environmental benefits of adaptation responses are often overlooked, unquantified, or undervalued, CCA fails to find a place in the community's priorities (Keefe, 2018).

Considering multiple adaptation benefits helps align investments with broader community needs, bridging short-term and long-term gains (Keefe, 2018; Mechler and Hochrainer-Stigler,

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2019; Heubaum *et al.*, 2022; Doeffinger and Rubinyi, 2023). Accounting for the multiple benefits of adaptation responses can enhance the acceptability and feasibility of climate resilience investments among policymakers and investors (Poljanšek *et al.*, 2017). Growing evidence shows that ancillary benefits from adaptation responses outweigh implementation costs (Rose, 2016; Mechler and Hochrainer-Stigler, 2019), with many of them being tangible and immediate (Rose, 2016) and surpassing conventional loss avoidance benefits (Mechler and Hochrainer-Stigler, 2019; Heubaum *et al.*, 2022; Rözer *et al.*, 2023). Indeed, building climate resilience can yield substantial benefits even if climate risks do not escalate (Doeffinger and Rubinyi, 2023). Identifying the multiple benefits of adaptation responses plays a crucial role in justifying decision-making to stakeholders at various levels (Tanner *et al.*, 2015; Mechler and Hochrainer-Stigler, 2019) and making climate resilience investments more compelling (Keefe, 2018; Heubaum *et al.*, 2022).

Notably, realising the full set of adaptation benefits presents a persuasive opportunity for decision-makers in both the public and private sectors to mobilise funds effectively, stimulate long-term climate resilience investment and set the foundations for improved monitoring and evaluation of ex-post intervention impacts (Tanner and Rentschler, 2015; Keefe, 2018; Fung *et al.*, 2021; Heubaum *et al.*, 2022; Rözer *et al.*, 2023). Realising the multiple adaptation benefits and considering them along the CCA planning cycle might hold the key to triggering the shift in decision-making — a transformative approach that not only enhances climate risk management but also fuels climate-resilient development.

While the Global Commission on Adaptation (GCA, 2019) and the World Bank (World Bank, 2021) stress the necessity for a deeper understanding of climate resilience interventions to respond to current and future climate change impacts effectively, framing climate resilience investments "only" to means for reducing damages and losses is insufficient to unlock the resources required to accelerate and scale up adaptation efforts (Mechler and Hochrainer-Stigler, 2019; Heubaum *et al.*, 2022). In order to do that, decision-makers are proactively calling for actionable and integrated approaches (Heubaum *et al.*, 2022; Rözer *et al.*, 2023).

On the one hand, an integrated framework can promote more equitable and efficient decision outcomes by facilitating an objective evaluation and comparison of adaptation options based on their performance and impacts across sectors and social groups (Heubaum *et al.*, 2022). Since governments and public institutions usually bear the burden of disaster losses, such a decision-making framework becomes more necessary as the changing climate induces more frequent, severe, and unexpected disasters (Rose, 2016). On the other hand, an operational framework can help the private sector understand how climate resilience investments return and create gains for individual enterprise activities, supply chains, and sectors with a more dynamic and stable economy (Rose, 2016; Heubaum *et al.*, 2022). Such a framework can help the private sector allocate resources effectively while contributing to social well-being, economic growth, and sustainable development (Doeffinger and Rubinyi, 2023; Rözer *et al.*, 2023). Therefore, it is urgent that CCA adopts a practical decision-making framework capable of accounting for the full potential of climate resilience investments, not only based on the wide range of benefits but also on unintended adverse effects and trade-offs[3]. In response to this need, this deliverable provides a practical framework for decision-making to deliver multiple resilience dividends in the CCA context, aiming to support decision-makers in identifying, evaluating, and selecting adaptation options better.

[3] For more information about related needs and gaps, see Annex 1- Gaps.

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2 Exploring the Multiple Dividends of Resilience

This section aims not only to inform but also to inspire, illustrating how resilience, when embedded in our systems and societies, can yield substantial, multifaceted benefits. In the forthcoming section, we introduce the resilience dividend concept (Section 2.1) and lay the foundational understanding of this pivotal idea. Following this, Section 2.2 delves deeper into the conceptualisation of the multifaceted benefits and outcomes of resilience and how these are deployed in the system. Section 2.3 illustrates these concepts through real-world examples in KCS, highlighting how resilience interventions produce multiple benefits. Finally, Section 2.4 broadens the perspective, showcasing the widespread and far-reaching positive effects of resilience across different societal areas and domains.

2.1 The Resilience Dividend Concept

In the context of resilience dividends, resilience can be understood as "*the ability of a system, community or society to pursue its social, ecological and economic development and growth objectives, while managing its [climate] risks over time in a mutually reinforcing way* (adapted from Keating *et al.*, 2017, p. 80)". It means that resilience is not just about "bouncing back", but rather "bouncing forward", adding a more forward-looking, proactive and dynamic perspective to the concept (Mechler and Hochrainer-Stigler, 2019) which aligns with the idea of CCA.

Based on this definition, climate resilience investments can unlock greater economic development as well as leverage progress on other social, economic and environmental goals (Rodin, 2014). For example, ecosystem restoration as an adaptation measure can yield a wide range of environmental benefits, such as biodiversity conservation, habitat creation, carbon sequestration, prevention of soil erosion and land degradation, and socio-economic benefits, which may include secure livelihoods, social cohesion, recreation areas, increased water security, enhanced food security, and tourism (Tanner *et al.*, 2015). When combined, these benefits can surpass the avoided losses and damages and, most importantly, the costs incurred in the rehabilitation process.

However, adaptation responses can have both direct benefits and adverse consequences (Figure 2), such as preventing asset losses or disrupting ecosystems and natural processes. Also, they can have indirect positive effects, such as job creation or negative ones, such as increases in food basket prices (World Bank, 2021). These indirect benefits, which are not directly related to the objectives of the intervention, are usually positive spillover effects extending across various domains (Rose, 2016). These additional benefits can be intended or unintended, immediate or long-term, tangible or intangible, resilience-specific or even collective for the society (Francis Vorhies and Wilkinson, 2016; Fung and Helgeson, 2017). Such benefits are simply synergies resulting from interconnected or overlapping objectives between climate resilience investments and other societal processes (Helgeson and O'Fallon, 2021). IPCC describes this as "*the positive effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits for society or the environment*" (IPCC, 2018, p. 546).

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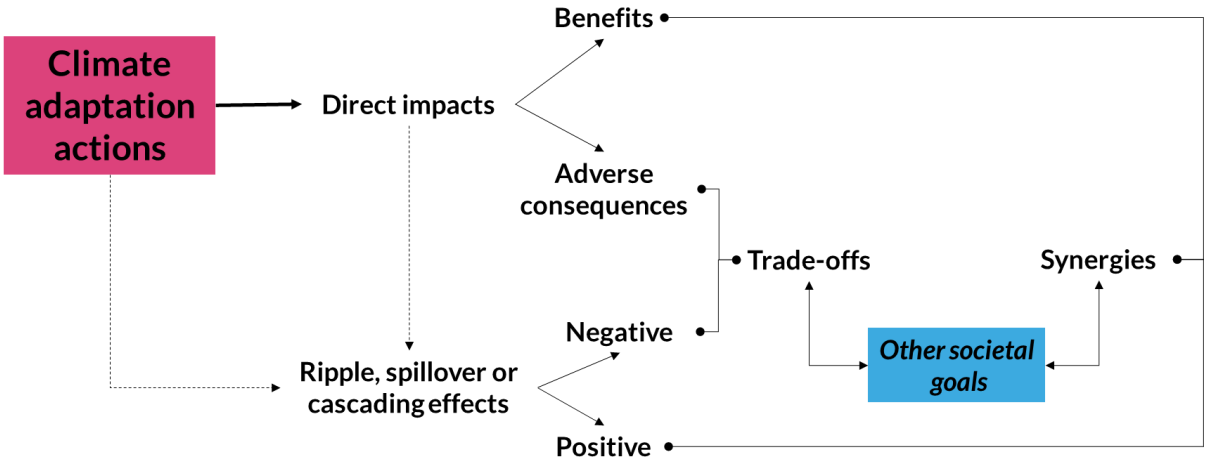

Figure 2. Representation of direct and indirect outcomes of climate adaptation actions

Due to direct and indirect adverse effects, climate adaptation actions also have unavoidable trade-offs. Adverse effects – often unintended, inadvertent, and thus unaccounted – harming, threatening or disturbing other systems, namely infrastructure assets, services, social groups, communities, ecosystems, projects, policies, institutions, organisations, sectors, regions, or overall society, can result in trade-offs (Rose, 2016). Trade-offs emerge from unavoidable adverse effects in the implementation of the adaptation response, compromising or hindering other societal objectives (e.g., sustainability, justice and equity) (Helgeson and O'Fallon, 2021). For example, in a coastal scenario, one community's construction of a protective seawall may shield it from rising sea levels but redirect related impacts to neighbouring areas that may experience increased erosion and flooding. In urban planning, addressing extreme heat events through green spaces and urban gardening initiatives may alleviate the heat stress but increase the water demand to sustain the newly established green areas, which might strain local water resources, especially in regions facing water scarcity. Furthermore, from a long-term perspective, promoting groundwater irrigation to address changing precipitation patterns in agriculture may boost short-term productivity, but it can lead to a depletion of groundwater resources over time, affecting water supplies for future generations. These examples underscore the intricate decision-making involved in balancing the intended and unintended effects of adaptation measures with potential trade-offs across communities, sectors, and generations.

In light of the above, the net benefits of resilience interventions (from risk reduction measures to adaptation responses) have been framed in the literature as Resilience Dividends (Rodin, 2014; Rözer *et al.*, 2023). Resilience Dividend refers to the net benefits of investing in resilience-building (Fung and Helgeson, 2017). Here, "net" means the differential impact of a resilience intervention compared to a pre-intervention scenario (Rodin, 2014; Fung *et al.*, 2021), which accounts for the full range of benefits, as well as for the implementation costs, adverse effects, and trade-offs. This balanced analysis of resilience dividends, in which overall positive and negative effects of adaptation actions are considered in the decision-making, can significantly improve adaptation planning.

2.2 What are the Multiple Dividends of Resilience?

Embracing the idea that adaptation responses may have Multiple Resilience Dividends (MRD) can unlock the full potential of resilience-building interventions, which can significantly have a positive impact on regions and communities. Adopting the MRD makes it possible to inform

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the achievement of multiple goals while addressing and managing risks effectively and sufficiently. Still, conducting real-life testing and exploring ways to apply it can further enhance its operationalisation.

Emerging examples of the MRD approach utilisation, mainly through the "Triple Resilience Dividend" (TRD), provide a conceptual and empirical basis to better inform the planning and decision-making of future adaptation strategies. Coming from the disaster risk management community, the TRD framework (Tanner *et al.*, 2015; Surminski and Tanner, 2016) offers a comprehensive approach to understanding the net benefits of investing in resilience interventions (World Bank, 2021), thus representing an opportunity to enhance resilience in diverse contexts (i.e., KCS in the context of the Adaptation Mission) and creating a strong case for resilience investments (Mechler and Hochrainer-Stigler, 2019; World Bank, 2021).

Figure 3 summarises the TRD framework. At its core, this framework recognises that resilience interventions deliver multiple benefits, grouped into three dividend categories (Surminski and Tanner, 2016; Fung and Helgeson, 2017; Heubaum *et al.*, 2022) as follows:

- The first dividend is the *avoidance of losses*, directly related to the nature objective of resilience interventions. This dividend refers to preventing direct and indirect risks, as well as reducing the immediate and long-run damages and losses of lives, livelihoods, and private and public assets, including also rapid and effective recovery from disasters (Tanner and Rentschler, 2015; Tanner *et al.*, 2015; Mechler and Hochrainer-Stigler, 2019). In contrast to the other two dividends, the first dividend only materialises when a disaster strikes.
- The second dividend encompasses induced *positive economic outcomes* and other *economic-related benefits* with the capacity to *unlock developmental potential*. This dividend is based on the idea that reducing background risks stimulates innovation, entrepreneurship, long-term investments, and development opportunities, resulting in sustained economic growth, even in the absence of a disaster (Tanner and Rentschler, 2015; Tanner *et al.*, 2015; Weingärtner, Simonet and Caravani, 2017).
- The third dividend comprises s*ocial, economic and environmental co-benefits* that contribute to the well-being of communities and the preservation of natural resources (Heubaum *et al.*, 2022). This dividend is based on the premise that most resilience investments can have multiple functions beyond reducing disaster impacts, regardless of whether the actual risk materialises (Tanner *et al.*, 2015). Co-benefits accrue in many forms by significantly contributing to the progress of other non-risk-related objectives (Tanner and Rentschler, 2015)—also called *synergies* (Helgeson and O'Fallon, 2021). For instance, investing in resilience generates positive social outcomes such as improved livelihoods, strengthened community cohesion, and enhanced social equity. Furthermore, these investments can create jobs, lower insurance premiums, increase property value, reduce infrastructure maintenance costs, and foster long-term savings in public and private budgets. Lastly, some resilience interventions, such as nature-based solutions, often lead to positive environmental side-effects, including ecosystem restoration, biodiversity conservation, and recovery of ecosystem services (Alves, Patiño Gómez, *et al.*, 2018; IPBES, 2022).

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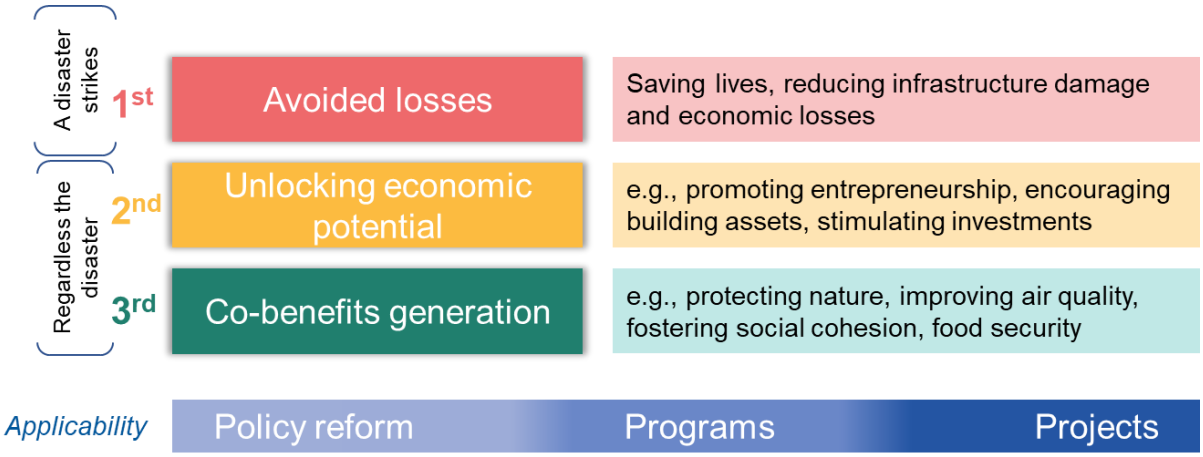

Figure 3. The Triple Resilience Dividend Framework (Based on: Tanner *et al.*, 2015; Surminski and Tanner, 2016; Mechler and Hochrainer-Stigler, 2019; Heubaum *et al.*, 2022)

The MRD concept builds on the TRD framework by allowing for greater flexibility and adaptability to different contexts, outcomes, and needs. Moving from the TRD to the MRD can enable a more comprehensive analysis of the effectiveness and performance of adaptation actions in relation to the local conditions and priorities. By removing the three fixed categories, the MRD concept provides a nuanced understanding of the wide impact of resilience-building measures while allowing various approaches for their characterization. In line with that understanding of the MRD concept, we propose that adaptation responses can deliver multiple benefits in a continuum (Figure 4), explained by three aspects: (1) temporality- benefits unfold at different periods, (2) receptivity- a benefit is subjective depending on who receives and perceives the effect of the intervention, and (3) interconnectedness- benefits cascade across sectors, scales and spaces depending on the strength of the connections between the system components, their interactions and interdependencies. Thus, the MRD considers resilience-building interventions and adaptation responses as a cross-cutting developmental aspect with effects beyond disaster risk management's scope.

Figure 5 provides a conceptual overview of how the effects of a climate adaptation response materialise. The climate adaptation response yields a spectrum of effects, encompassing both direct and indirect, positive and negative outcomes. The materialisation of these effects into either benefits or adverse consequences hinges on the local context, shaped by its climate risks and development challenges. Within this context, there are various sub-systems, such as economic sectors, households, social organisations, communities, public institutions, or ecosystems, and each has distinct priorities, needs, and specific goals. The nature of the interconnectedness and positioning of these sub-systems relative to the targeted intervention area or sub-system determines how these benefits and adverse consequences cascade across the systems and the space, creating a chain of primary, secondary, and tertiary effects. As the adaptation response persists, diverse effects unfold during the intervention´s lifetime, ranging from immediate to long-term consequences. Acknowledging that an adaptation response may not cover all the climate risks nor address a specific risk comprehensively, there may still be residual risks that require additional interventions. Additionally, the inherent trade-offs resulting from inevitable adverse consequences or unforeseen changing conditions can give rise to emerging risks that require attention. Collectively, these residual, unaddressed, and emerging risks translate into future adaptation needs that will lead to new adaptation responses.

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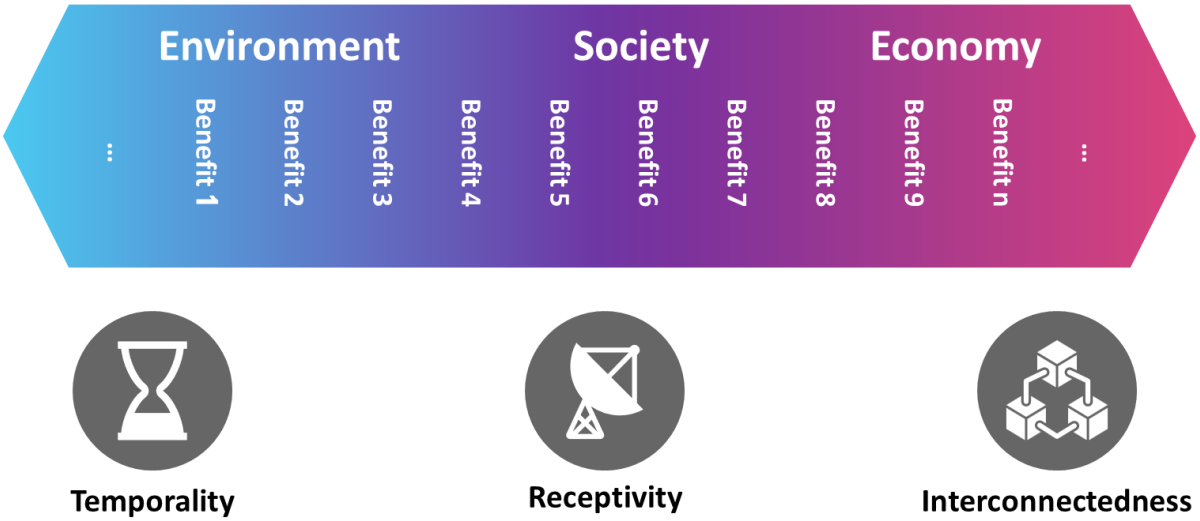

Figure 4. Benefits as a continuum

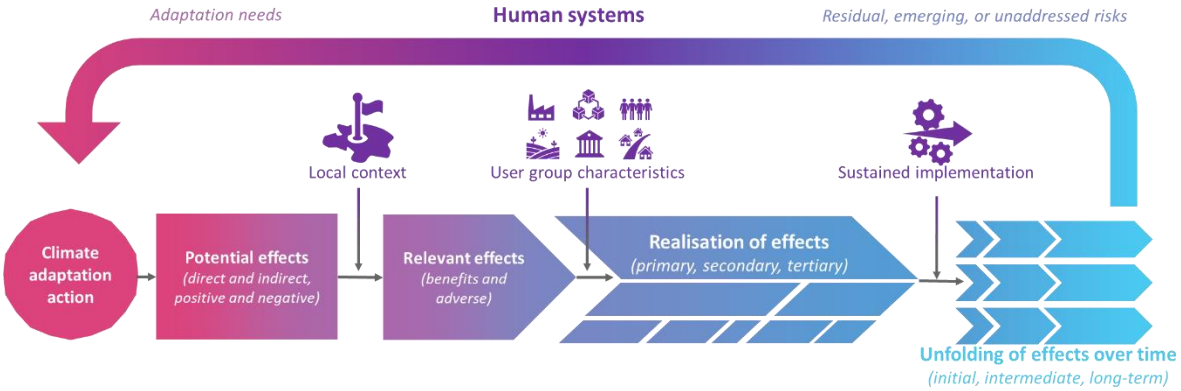

Figure 5. Realisation of multiple benefits and adverse effects from adaptation responses

The MRD conceives adaptation as interventions that impact various sectors, such as food, land-use, water, health, energy, or ecosystems, on different domains (e.g., social, economic, cultural, environmental, institutional, political, and technological). The MRD comprehensively examines the effects (positive and negative) and implications (risks-related and development-related) of adaptation measures in relation to the system and its various components. For example, an adaptation measure can improve the quality of life, foster energy, food and water security, support ecosystem functioning and health, or have other benefits that span different sectors and domains.

2.3 Examples of Resilience Dividends in Key Community Systems

Many adaptation responses show resilience dividends that are realised within specific sectors. Kwy Community Systems (KCS) are areas of transformation and innovation defined by the European Climate Change Adaptation Mission Implementation Plan (European Commission, 2021a). KCS are present on a regional and community level as they cover areas of basic needs that are increasingly also impacted by climate change. KCS are highly interconnected, implying several interdependencies and many potential cascading effects from one system to

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others. Thus, resilience dividends that unfold across systems instead of within KCS are the rule rather than the exception.

In the following sub-sections, KCS-specific benefits will be explained through examples followed by benefits unfolding across systems.

2.3.1 Critical Infrastructure

Adaptation responses in critical Infrastructure can deliver a variety of benefits. For example, levees and protective dams can provide resilient roadways and transport routes (Tanner *et al.*, 2015). Super dikes in Japan, for instance, differ in their wide base and gentle slope compared to normal dikes and can thus provide additional benefits such as resistance to erosion and earthquakes, aesthetics, recreation (e.g. easy public access to water) or urban development (C40 Cities, 2016; Fraser Basin Council, 2023).

Further, Tanner et al. (2015) have argued that the construction of safe seaports against extreme weather events can serve as a hub for developing fisheries logistics services and better infrastructure. Also, repurposing cyclone shelters in Bangladesh and Papua New Guinea in the absence of natural hazards has been shown to provide safe buildings which can be used, e.g. for educational, social and health purposes (Shah Alam Khan, 2008; Tanner et al., 2015).

2.3.2 Health and Wellbeing

Besides the main objective of adaptation interventions to guarantee the physical integrity of human beings, many adaptation responses go beyond targeting the immediate impacts of natural hazards. However, health benefits are among the least studied adaptation responses (Sharifi *et al.*, 2021).

Cities and towns trying to tackle the Urban Heat Island effect by introducing urban greenery solutions follow a promising path to alleviate heat stress from its citizens (e.g. Zölch *et al.*, 2016; Wong *et al.*, 2021). This is accompanied by several resilience dividends which the adaptation intervention may provide. For instance, the case of post-Hurricane Sandy in New York City has shown that urban greenery benefits realised in "*recreation, activities, socialization, and environmental engagement* (…) [supporting] *place attachment and social ties*" (Campbell et al., 2016, p. 34).

In an extensive review Sharifi *et al.*, (2021) have shown that urban climate change adaptation measures (ranging from infrastructure to nature-based solutions and governance) result in various health benefits such as reduction of cardiovascular and respiratory diseases, heat stress, exposure to food and water-borne diseases, and improved mental health.

2.3.3 Ecosystems and Nature-based Solutions

Many adaptation responses protect, restore and create habitats while making biodiversity thrive. Nature-based solutions such as green infrastructure and urban greenery facilitate many opportunities for ecosystems while providing benefits to society (e.g. health and wellbeing). Restoration of habitats can, for instance, benefit pollination, regulate (micro-)climate, provide freshwater, stabilise soil ecosystems or control pests (IPBES, 2022) and simultaneously contribute to recreational spaces for communities.

A case study of wetland protection and restoration for flood reduction in Sri Lanka shows that it contributed to regulating climate, water and soil erosion, pollination and nutrient cycling while providing habitats for species (Tanner et al., 2016).

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2.3.4 Water Management

Water is a fundamental resource across sectors, so adaptation responses in the Water Management systems can deliver multiple resilience dividends. For example, urban stormwater management systems can not only secure water supply in pre- and post-dry seasons, but also abate water pollution, provide recreational spaces, and reduce temperature on hot days (Heubaum *et al.*, 2022). Further, many interventions in the Water Management system are strongly related to agriculture, which is increasingly threatened by drought risks. For instance, modern irrigation systems in agriculture developed for facing water scarcity can additionally reduce soil erosion, positively contribute to deforestation (Francis Vorhies and Wilkinson, 2016), and tackle agrichemical pollution (e.g., nitrogen pollution, heavy metals) while increasing crop productivity (Heubaum *et al.*, 2022). Another example of additional benefits concerns the case of decentralised water management in Mexico City, which aims at a "*sustainable water equilibrium*" (Chelleri, Schuetze and Salvati, 2015, p. 125) through treating wastewater and supplying freshwater for human and agricultural purposes. Further, however, this approach has shown that communities profited significantly from the intervention through shifted responsibilities (ibid).

However, many interventions provide benefits to the Water Management system. For instance, besides its primary heat reduction benefits, urban greenery and green infrastructure can contribute to the management of water runoff during extreme events, improve water body quality and aquifer status or provide water sources for rich biodiversity (Alves, Patiño Gómez, *et al.*, 2018; Sharifi, 2021) which connects water management with ecosystem functioning and service provision.

2.3.5 Land Use and Food Systems

Climate change poses a growing threat to Land Use and Food Systems, making it necessary to develop adaption strategies. Climate-smart Agriculture is an option for ensuring agricultural sustainability and resilience (Lipper and Zilberman, 2018). Farmers aim to sustainably increase productivity and adapt to climate change while reducing emissions or even removing carbon from the atmosphere (FAO, 2023; World Bank, 2023), thus contributing to long-term resilience in Land Use and Food Systems. Applying technological developments such as satellite information provides more than climate information for crops as communities also benefit from the educational aspect or generate knowledge relevant to insurance programs (Basist *et al.*, 2018). Additionally, climate-smart agricultural practices in Central Asia have been shown to deliver economic benefits for poor and wealthy households "*with improved access to markets and agricultural extension services*" (Mirzabaev, 2018, p. 477).

Other adaptation options, such as reforestation and sustainable forest management, exemplify climate adaptation responses against various climate-related risks (e.g., floods, storms, droughts, heat waves, and wildfires) that can provide additional benefits to the whole system and beyond. Those benefits may include biodiversity increase, reduced soil erosion, reduced carbon sequestration, and improved air and water quality (Chastin *et al.*, 2021), which can positively impact many societal processes and goals like climate change mitigation (ibid), public health or nature conservation.

2.3.6 Local Economic System

Adaptation and resilience strategies in the economic system typically entail, among others, changes in capital investment and enhancement, adjustments in relevant norms and regulations or reshaped enterprise management (Chambwera *et al.*, 2014). Concrete adaptation interventions such as insurance schemes, climate risk pooling or bonds have been

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shown to deliver additional benefits, especially for small and medium-sized companies (Więckowska, 2013; Banga, 2019; Asian Development Bank, 2022). Benefits that go beyond their economic adaptation purpose have been discussed and observed with regard to the general risk distribution in society, an increased understanding of current and future risks, welfare securitization for current and future generations or contribution to the achievement of sustainable development goals (Chambwera *et al.*, 2014; Surminski, Bouwer and Linnerooth-Bayer, 2016; Mhlanga, 2022).

Due to its cross-cutting character, the local economic system can benefit from adaptation responses in other KCS mentioned above. Resilience building and risk minimisation in other KCSs can act as a positive economic stimulant and provide a "*safe economic environment*" by reducing background risk emerging from natural hazards (Tanner et al., 2015). For example, including risk financing instruments and insurance schemes can significantly reduce uncertainty and simultaneously unlock private investments, jobs and growth (Griffith-Jones and Tanner, 2016). Similarly, water irrigation systems to face drought in Jamaican agriculture yielded economic benefits through increased productivity, while wetland protection for flood management in Sri Lanka provided economic prosperity for fishing and rice cultivation (Vorhies and Wilkinson, 2016; Tanner et al., 2016).

Benefits in the form of positive stimulation and security provision can also be realised in the increase of urban property values and revenue streams which stem from, e.g. tourism or business taxes (Hallegatte, Bangalore and Jouanjean, 2016; Beltrán, Maddison and Elliott, 2018). While the increase in urban property prices and revenues need to be monitored and used carefully, they can also create additional jobs and contribute to socio-economic development (Tanner et al., 2015; Ommer et al., 2022). The case of Natura2000 sites provides an example of benefits for the local economic system: Between 2006 and 2010, expenditures from tourism and recreation reached 50-85 billion Euro creating between 4.5 and 8 million full-time jobs (Trovato, Micalizzi and Giuffrida, 2021).

2.4 Examples of Resilience Dividends across KCS

The previous examples of adaptation interventions demonstrate that most adaptation responses go beyond delivering resilience dividends for one KCS, thus pointing to an often-systemic impact. Nature-based solutions are generally good examples of adaptation responses that deliver resilience dividends across KCS, as they tackle the direct impact of a natural hazard while stabilising the local economic system through reducing background noise and providing other benefits to nature and society (Tanner *et al.*, 2015). For instance, Urban Greenery and Green Infrastructure provide many benefits within and across several KCS, such as ecosystem resilience, (coastal) flood protection, carbon storage, energy use and heat stress reduction or water management possibilities (Choi, Berry and Smith, 2021). Other studies mention that green spaces can "*further support social cohesion and inclusion*" (Ommer et al., 2022, p. 2) by providing recreational or gastronomy spaces (Raymond et al., 2017).

Two case studies described by Vorhies and Wilkinson (2016) illustrate that similar Nature-based Solutions targeting flood risk reduction can provide very different benefits depending on the implementation context. Mangrove planting in Vietnam mainly delivered environmental and economic benefits such as "*carbon sequestration, nutrient retention, sediment retention, biodiversity habitats, flood attenuation, wastewater treatment and water supply and recharge*" (p. 68). The number of beneficiaries profiting from this intervention (350.000 directly and 2 million indirectly) demonstrates the opportunities for resilience dividends to unfold across scales. On the other hand, besides reducing flood risk, wetland protection and

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restoration in Sri Lanka delivered additional benefits by providing livelihoods and recreational areas, economic security (fishing, rice cultivation), heat mitigation (health benefits, energy savings) while contributing to the maintenance of ecosystem functioning and services (treatment of wastewater, freshwater provision, carbon sequestration, regulation of climate, water and soil, pollination and nutrient cycling).

Another example of benefits unfolding across KCS is the reduction of drought risk. As mentioned above, the KCS of Land Use and Food System is strongly interlinked with other KCS, showcasing a continuum of societal benefits. The case study of a Jamaican agriculture irrigation project described by Tanner *et al.* (2016) shows that the (local) economic system heavily profited from increased productivity while social (training, learning, building comradeship, recreation) and environmental benefits (wastewater treatment, maintenance of fresh water supplies, carbon sequestration, climate and water regulation) unfolded concurrently.

The case studies show that the realisation of adaptation responses seldom unfolds in KCS-specific benefits but rather provides a broad set of resilience dividends. Further, KCS can transfer their gains in resiliency to other KCS due to their strong connection. Sharifi et al. (2021) describe a case where resilient Critical Infrastructure is directly connected with a better provision of services for the health and wellbeing of citizens. Therefore, cross-sectoral resilience dividends usually result in valuable outcomes for several social groups or a whole community, thus adding to their resilience.

In essence, the MRD approach supports mainstreaming climate adaptation and resilience into development agendas and prioritises transformative, systemic, sustainable, and long-term resilience-building interventions. Adopting the MRD approach can inform decision-making better while building systemic resilience as a transformative strategy for sustainable development.

3 Methodology

The objective of this deliverable is to develop a practical decision-making framework for local and regional authorities, focusing on delivering MRD in KCS. To steer the research and development process, the following overarching question was posed: *How can the concept of multiple resilience dividends be integrated into the adaptation decision-making of European regions across KCS?* To systematically address this question, the construction of the MRD framework unfolded in three distinct stages (Figure 6), aiming to harness the most updated knowledge on climate adaptation and resilience, systems thinking, and decision-making.

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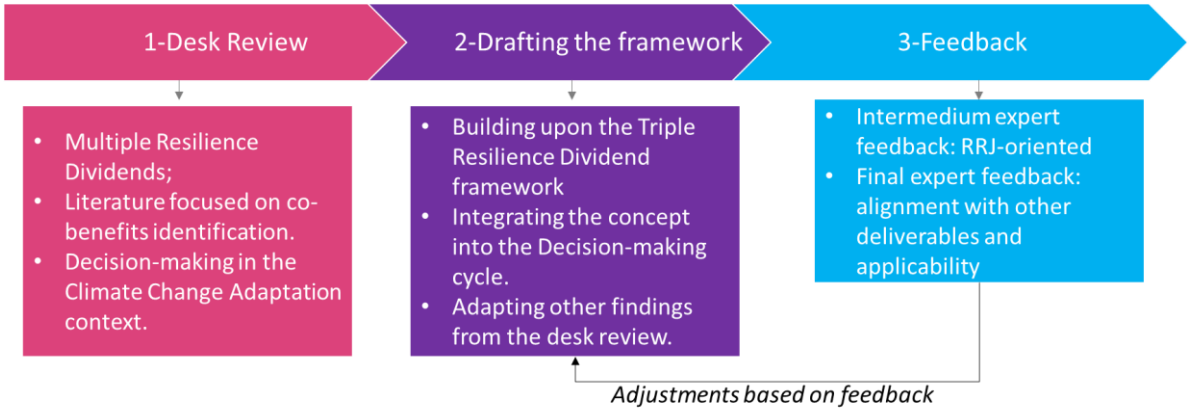

Figure 6. Methodological approach to develop the MRD framework.

(I) Literature Review:

The initiation of the methodology involved an in-depth examination of 28 articles centred around the resilience dividend concept, sourced from the Scopus database, searching within title, abstract and keywords using the following terms: "resilien*" and "*dividend**". This review aimed to delineate the state-of-the-art, highlighting existing challenges and limitations related to the applicability of the resilience dividend concept. Additionally, 50 articles were sourced from Scopus, scrutinising across diverse fields such as climate mitigation, ecosystem conservation, and decision sciences (*see* Annex 2- *Data collection and analysis*, Part A). This supplementary review aimed to discern how various disciplines assess additional benefits and adverse effects—exploring methods, tools, and best practices influencing decision-making. Each of these articles was reviewed using Content Analysis (Berg, 2006; Bernard, 2013), classifying the information in a coding structure tailored to the purpose of this Deliverable (*see* Annex 2- *Data collection and analysis*, Part B).

(II) Drafting the Framework:

Building upon the TRD framework and extensive literature review described above, an initial draft of the MRD framework was developed. This draft involved the integration of the MRD concept into the decision-making cycle[4] of the existing Regional Adaptation Support Tool (RAST), while adapting relevant aspects of other decision-making approaches in Climate Risk Management (GIZ, 2021), Adaptive Management (Allen et al., 2011), Robust Management (Groves et al., 2013), and Complex Problem-Solving (Chevallier, 2016). Additionally, it was enriched with relevant insights from other disciplines in the evaluation of interventions and the identification of benefits, adverse effects and trade-offs gained from the literature review (e.g., Grafakos, Gianoli and Tsatsou, 2016; Raymond et al., 2017; Thiault et al., 2020; IPBES, 2022).

(III) Expert Feedback:

The initial MRD framework was subject to scrutiny through two iterative feedback rounds from a diverse multi-disciplinary expert group composed of P2R project partners. This group encompassed experts from diverse backgrounds, spanning economics, social science, geography, ecology, engineering, political science, business management, risk analysis, and climate science. The first feedback round provided input that helped shape the framework

[4] The RAST cycle consists of six steps: 1- preparing the ground for adaptation, 2- assessing climate change risks and vulnerabilities, 3- identifying adaptation options, 4- assessing and selecting adaptation options, 5- implementing adaptation, and 6- monitoring and evaluating adaptation.

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along the intervention logic of the P2R—Regional Resilience Journey (RRJ). The second feedback round further refined the framework to ensure alignment with other P2R deliverables and enhance the framework´s practical value.

4 The Decision-Making Framework

This section presents the MRD framework in four sub-sections. It begins with an explanation of the context of the implementation in Section 4.1, followed by the presentation of the "Building Blocks" that form the foundation of this framework in Section 4.2. Subsequently, Section 4.3 offers a practical example of the framework's application through a synthetic case study. Finally, Section 4.4 provides an overview of the methods and tools used to characterise MRD. Collectively, these sub-sections offer a scholarly and analytical approach to understanding and applying MRD concepts in the context of transformational adaptation.

4.1 Context of Implementation of the Decision Framework

Considering the scope of P2R, the MRD framework is developed in the context of local and regional climate change adaptation and system transformation in Europe. Target users, applicability, and expected outputs are thus concordant with this context. The primary audience for this framework comprises decision-makers operating in both the public and private sectors at the local and regional levels. The framework is designed to be flexible and adaptable enough to address the varied needs of these stakeholders, recognising the diverse societal roles, responsibilities, priorities and perspectives within the actors and the sectors. Beyond P2R, the framework and the thinking it introduces can be useful for other types of stakeholders.

The MRD framework aims to ensure that adaptation-related decisions contribute to catalysing the system's transformation, climate resilience, and sustainable development. It prioritises transformative adaptation responses that enhance systemic resilience and human well-being by inducing a long-term perspective in decision-making and considering CCA as cross-cutting developmental opportunities. Through the framework, decision-makers can transcend the traditional focus on CCA and DRR and have a more effective, sustainable, and impactful decision-making process.

The framework does not aim to impose a singular approach to decision-making. Instead, it fosters a dynamic and inclusive environment, allowing decision-makers to choose the most relevant criteria to their specific context. The framework refrains from dictating what should be included or excluded, promoting a customised and adaptable decision-making process that aligns with the unique circumstances of each region. In light of that, the framework recognises and respects decision-makers' autonomy in tailoring the approach to their specific needs, capacities and contextual requirements.

Distinct from a standardized solution, the framework is envisaged to be a versatile instrument applicable throughout the entire project lifecycle — from initial planning stages to monitoring and evaluation. Moreover, the framework offers multiple entry points for the varied regional resilience levels. This flexibility acknowledges the heterogeneity in the resilience maturity levels across regions, considering that some regions may have already made some progress in terms of adaptation, disaster risk reduction, and resilience-building.

Within the broader context of P2R, the MRD framework is seamlessly integrated into different steps of the RRJ—except for the implementation steps, which fall outside the scope of P2R. Still, decision-makers and implementors are encouraged to consider the framework

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during the intervention planning and implementation, as explained in this section later. A detailed overview of how the MRD framework fits into the RRJ is given in Section 5.1.

4.2 Building Blocks of the Decision Framework

The MRD framework (Figure 7) is structured around three cross-cutting pillars: Choices, Participation, and Approaches. Besides that, the framework follows the eight key Steps of a conventional decision-making cycle and deploys them in an iterative process for improvement. Those building blocks are explained below.

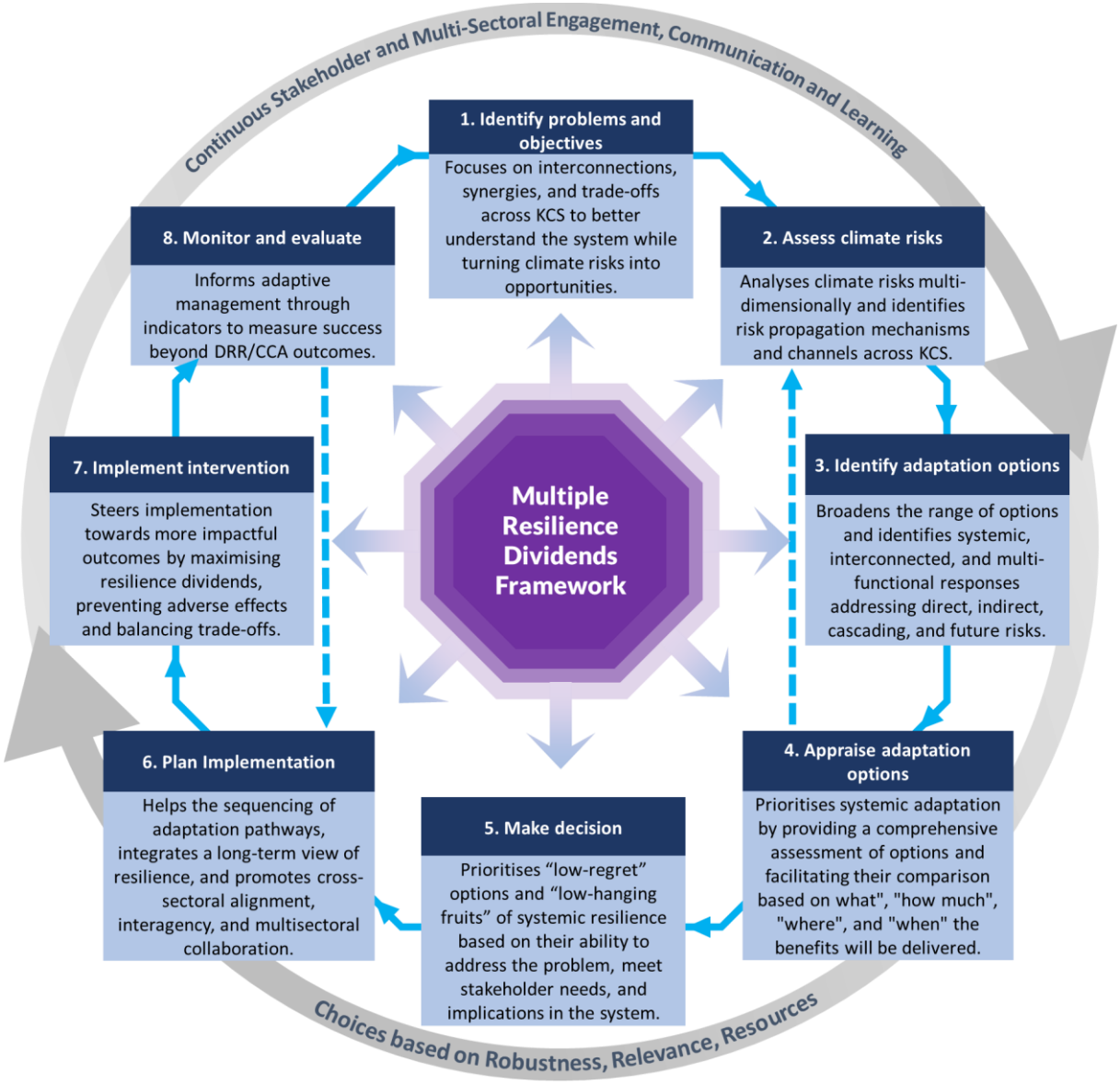

Figure 7. Framework to deliver Multiple Resilience Dividends[5], enhancing key aspects of the adaptation planning cycle.

[5] Please note that the graphical representation of the MRD framework presented in this figure is not intended to be shared with the regions as an alternative to the Regional Resilience Journey (RRJ) approach developed as an overarching framework to be used by regions included in the P2R cascading funds. The purpose of this image is to guide the reader through the logic of MRD thinking and how it informs decision-making processes. A detailed discussion on how MRD thinking informs and feeds into RRJ is given in Section 5. Furthermore, at the time of the development of the framework and the iterative process of feedback collection, the final version of the RRJ was still not available. Thus, the authors opted to discuss the integration in a separate section (Section 5).

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4.2.1 The MRD in the Decision-Making cycle

The MRD concept as a central piece of the framework redefines each of the eight steps of the decision-making cycle as follows:

(1) Identify problems and objectives.

This step consists of a comprehensive exploration of the current and potential impacts of climate change on a specific region or system, as well as an understanding of a wider planning, policy, social, environmental, and fiscal context. The aim is to define the decision-making context, which involves understanding the challenges posed by climate change, analysing how these relate to local contexts and procedures, and defining clear objectives for reducing and adapting to climate-related risks, including leveraging synergies emerging from adaptation responses and resilience actions.

On the one hand, defining the decision-making context involves the integration of values and perspectives of a wide diverse range of stakeholders, including local communities, businesses, scientists, NGOs, authorities and policymakers. On the other hand, it involves defining the scope (temporal, geographical, and sectoral), boundaries (the level of associated uncertainty, limits of available resources, and external constraints), space (authority, capacity, and functions), and governance aspects of the decision-making process (e.g., institutional and financial architecture).

The MRD framework can change the narrative and build a compelling case for investing in resilience by re-addressing climate risks as opportunities. It encourages thinking beyond isolated problems (e.g., single sector-focused thinking) and focuses on the overlaps between sub-systems (i.e., KCS) outside the problem domain. This approach broadens the system boundaries by adopting a multisectoral and cross-sectoral perspective, emphasising interconnections, trade-offs, and synergies across KCS and related priorities. As the scope of analysis expands, so do the objectives of the decision-making process. This helps ensure that adaptation responses align with overlapping cross-KCS goals and target underlying drivers of risks while increasing their chances of building resilience to climate change more effectively.

What are the required inputs?

- Stakeholder input: perspectives of climate impacts, and cross-sectoral linkages.
- Climate change information: scientific data, expert input on climate change, local information, and observations about past and ongoing climate-related impacts.
- A detailed overview of existing stakeholders, sectoral policies, funding streams etc.

What are the expected outputs?

- Clearly defined objectives to address a particular climate-related problem cross-sectorally, considering interdependencies between different elements (e.g, sectors, policies, administrative boundaries).

Key activities:

- Specify timeframes relevant to the decision, considering both short- and long-term impacts.
- Stakeholder mapping and take stock of existing institutions, policies, and funding sources.
- Clearly outline the boundaries of the decision-making process, specifying the geographic, sectoral, and thematic scope of the issue to address.
- Establish the limits and constraints within which the decision-making process will operate.
- Identify external factors, regulations, or constraints that may affect the decision space.
- Recognise the limitations and uncertainties that influence the decision space.
- Set the ways to engage and communicate with the stakeholders.
- Agree on the decision-making criteria and how to balance trade-offs in procedural choices.

Box 2. Key inputs, outputs, and activities of Step 1 ' Identify Problems and Objectives'

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(2) Assess climate risks.

Assessing climate risks involves thoroughly understanding risk components (i.e., hazard, exposure, vulnerability) in a given context and examining the potential impacts and challenges posed by climate change on a given region or system. This step evaluates the likelihood, severity and evolution of climate-related risks regarding the identified problems and objectives and prioritises areas, sectors or groups based on the level of risk. By doing that, decision-makers can address the most urgent and impactful threats while setting the foundation for developing effective and efficient adaptation responses.

The MRD framework provides a more comprehensive and systematic approach to assessing climate risks. In today's complex risk landscape, sectors are not isolated entities; changes, shocks, or disruptions in one sector can have ripple effects on others. Sectors interact and influence one another through societal drivers and physical connections, allowing risks to be transmitted across the system. Thus, the framework acknowledges that climate risks can propagate across KCSs, much like benefits do through cascading and indirect impacts.

Integrating multi-sectoral perspectives regarding climate change risks acknowledges the dynamic nature and diverse facets of related risks. The framework takes a multi-dimensional perspective beyond assessing material damages and includes non-economic and indirect impacts. By doing so, the framework helps identify additional elements that can be overlooked but are exposed and vulnerable to hazards and climate effects.

Moreover, the MRD framework accounts for the dynamic nature of risks, recognising that adaptation responses can have varying effectiveness and benefits over different timescales. Insights gained from analysing multi-sectoral synergies and trade-offs in adaptation go beyond conventional risk assessments, offering a longitudinal perspective that informs decision-makers about potentially emerging risks and future maladaptation. That is why the framework fosters a proactive and iterative approach to climate risk assessment once adaptation options are identified and appraised. It considers indirect risks, the adverse effects of interventions, the risks of not taking any action, and the potential loss of opportunities.

Additionally, future scenarios can be better developed by analysing how the benefits of adaptation responses will influence risk factors over different periods, shaping the evolution of current risks and forthcoming risks. This approach provides a more nuanced understanding of important factors such as residual risk, adaptation limits, and adaptation needs, where the evolving nature of climate risks can be navigated through the system's interconnectivity.

What are the required inputs?

- Data: vulnerability, exposure, hazards, and historical climate data.
- Stakeholder input: previous risk experiences, adaptation capacity, sensitivity to risks, risk tolerance, and risk perception.

What are the expected outputs?

- Plausible future climate scenarios for the region and risk projections.
- Key risks that must be addressed urgently.

Key activities:

- Analyse historical climate events in the region, their impacts, patterns and trends.
- Model risk scenarios based on climate and socio-economic changes.
- Assess the likelihood and severity of climate-related risks (incl. cross-sectoral and cascading risks) at different timeframes and under various scenarios.
- Identify risk hotspots and prioritise risks with stakeholders and those primarily impacted.

Box 3. Key inputs, outputs and activities of Step 2 'Assess Climate Risks'

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(3) Identify adaptation options.

Identifying adaptation options involves generating a range of strategies and actions that can address the identified climate risks. This step aims to explore diverse approaches to enhance resilience and spot adaptation measures across various sectors and at different levels (e.g., from individual to regional). By engaging experts, stakeholders, and community members in co-generation processes, this step ensures that a wide set of potential actions, including both "hard" (e.g., infrastructure) and "soft" (e.g., policy) options, are contextually appropriate. Importantly, this step sets the stage for a more concentrated evaluation and thorough decision-making process in the subsequent steps.

The MRD framework notably improves the identification of options and proactively prompts option screening. As the system (i.e., the context of decision-making) expands, decision-makers can consider a wider range of adaptation options and comprehend the potential synergies among KCSs that result from reducing climate-related risks—the primary objective. Therefore, the MRD framework fosters thinking more of interconnected responses, systemic interventions, adaptation packages of complementary and compatible measures, and multi-functional solutions aiming to address not only direct risks, but also the indirect, cascading, and future ones.

To do that, the MRD framework induces the participation of a broad range of stakeholders. It aims to diversify the group of participants involved in decision-making by actively seeking multi-sectoral engagement based on the premise that adaptation benefits extend beyond a single sector and ripple out far beyond the initially targeted intervention.

What are the required inputs?

- Scientific research, empirical evidence, existing plans, expert opinions, and stakeholder consultations.

What are the expected outputs?

- List of potential adaptation options relevant at various scales, from local to regional, consisting of a wide range of intervention types (e.g., nature-based, early warning systems, grey infrastructure, institutional mechanisms, policy measures, awareness-raising, etc.), including options with both short- and long-term outcomes.

Key activities:

- Facilitate brainstorming sessions with experts, stakeholders, and community members to generate a range of potential strategies.
- Involve representatives from various sectors and community groups, and ensure their ideas and perspectives are considered.
- Incorporate feedback from all relevant stakeholders, including input from local communities based on local and traditional knowledge as well as their preferences.
- Map previous adaptation efforts, and identify successful cases and lessons learned.
- Encourage creative and systemic thinking, fostering innovative and diverse adaptation options (e.g., multifunctional, combined, synergistic or interconnected measures).

Box 4. Key inputs, outputs and activities of Step 3 'Identify Adaptation Options'

(4) Appraisal of adaptation options.

The appraisal of adaptation options involves analysing the applicability of each identified adaptation measure and its potential performance against the identified risks, including overall benefits, adverse effects and trade-offs. This step helps decision-makers to prioritise options that offer the best balance of effectiveness, cost-efficiency, and social acceptance, ensuring that the selected responses are well-suited to the specific context and goals of the adaptation process. Given its emphasis on co-benefits and trade-offs, the appraisal of

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adaptation options under their capacity to deliver MRD makes an important contribution to formulating adaptation pathways[6], serving as evaluation criteria.

The MRD framework is crucial to building a strong case for systemic adaptation during the options appraisal. It prioritises interventions that perform better and yield more significant results at the system level over those working in isolation and with fragmented and narrowed impacts on overall resilience. To do so, the framework encourages decision-makers to analyse adaptation options in two directions comprehensively. The first direction entails evaluating how the benefits of an adaptation measure could contribute, both directly and indirectly, to the achievement of risk reduction objectives and other sectoral or societal goals – that is, identifying potential synergies. The second direction involves examining how the inevitable adverse effects of a given measure could affect different sectors, groups, or systems in varying ways. This analysis will permit decision-makers to identify potential trade-offs, such as the need to make a critical decision to address an immediate problem, which could have negative long-term consequences or vice versa. In that way, the framework quantitatively and qualitatively evaluates options against overlapping, cross-cutting, and multisectoral priorities and objectives, extending beyond the DRR/CCA focus.

Importantly, the MRD framework considers the viability, suitability and feasibility of adaptation options in this step. In terms of viability, the framework assesses the capability of an adaptation option to effectively work for the identified risks (adaptation-related objective) and address the underlying drivers of system vulnerabilities (synergies and trade-offs). This means that the framework evaluates how effectively the adaptation options enable or constrain the achievement of not only adaptation outcomes (i.e., build resilience to climate change and harness opportunities), but also other relevant societal goals (e.g., poverty alleviation, inclusion, water and food security), and the envisaged transformation of the system[7]. To do that, the framework evaluates options comprehensively, considering their full spectrum of benefits and adverse effects, including potential trade-offs, conflicts, and maladaptation risks. This allows decision-makers to compare options and determine 'what', 'how much' and 'when' benefits will be delivered, evaluating the option's performance and overall resilience gains under different climate scenarios.

Regarding suitability, the framework examines the appropriateness of adaptation options given the local conditions and dynamics. It integrates stakeholder perceptions and priorities as part of the options evaluation, taking into account what benefits are relevant and to what degree. Thus, it helps map specific communities, KCS, or areas where adaptation options are suitable, considering both the local biophysical and climatological characteristics, as well as the socio-economic and cultural aspects.

Furthermore, the framework considers the feasibility of adaptation options by identifying their enabling environment and challenges related to implementation. It is widely recognised that adaptation responses perform better in favourable environments, meaning when the system has adequate financial, technical, institutional, social and political conditions to operate efficiently and sustainably in the long run. Therefore, it is assumed that the yield and unfolding of the benefits range of each adaptation option will depend on the available resources, technology, governance structures, public acceptance and institutional capacities that it requires. Hence, for the MRD framework, it is essential to choose adaptation options

[6] For the application of pathways thinking in the context of P2R, *see* Deliverable 6.2 – Methodologies for adaptation pathways formulation

[7] Bond *et al.*, (2017) explain the importance of resilience interventions in enabling institutional reform, behavioural change and, in some cases, system change.

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that can harness the existing conditions so they can deliver the expected dividends realistically.

Overall, the MRD framework allows decision-makers to comprehend how adaptation responses can catalyse the achievements of other societal goals and development priorities while reducing risks across multiple sectors, building resilience to climate change, and fostering the system's transformation by incorporating other relevant criteria for selecting interventions.

What are the required inputs?

- Stakeholder input: relevance of the benefits delivered by each measure, preferences for certain interventions, and local capacity for potential adoption.
- Technical information: effectiveness, feasibility, and other relevant criteria (e.g., cost, social acceptance, political alignment).

What are the expected outputs?

- Intervention performance profile (benefits and co-benefits, adverse effects, trade-offs, effectiveness at different timeframes and levels, factors enabling or hindering implementation, cascading effects across the systems).
- Ranking of adaptation options based on pre-defined criteria with the primary objective of climate risk reduction.

Key activities:

- Conduct a comprehensive feasibility assessment of each option (e.g., environmental, social, economic, institutional, technical).
- Identify the benefits and co-benefits, adverse effects, and trade-offs of each option in relation to the identified risk and adaptation needs.
- If possible, iterate the risk assessment by looking at the influence of a particular adaptation response on the risk factors (e.g., maladaptation).
- Identify the enabling environment and challenges of each option, as well as its flexibility to changing conditions (uncertainties) in future scenarios.
- Rank the different adaptation options based on pre-defined criteria, filtering out impractical, unfeasible, or unrealistic options.

Box 5. Key inputs, outputs, and activities of Step 4 'Appraise Adaptation Options'

(5) Make decision.

The decision-making step involves synthesizing information from the appraisal process, stakeholder preferences, and policy considerations to select the adaptation options that better fit the identified problems and objectives. This step requires balancing technical, economic, environmental, social, and institutional aspects to make an informed and effective decision. The selected options should comprehensively address the most pressing challenges posed by the changing climate in the context of the region or system in line with policy objectives and stakeholder priorities. It is thus essential to ensure continuous stakeholder engagement that fosters support for the adaptation process and considers equity and justice while choosing the options.

The MRD framework exploits systems thinking to recognise '*low-regret*' options - those that offer the most benefits with the least adverse effects. It helps distinguish these from options that may lead to regrets, such as those that harm the environment severely, disproportionately impact certain social groups, are expensive in the long run, have economic consequences for the region, disrupt local cultural practices, conflict with existing policies, are resource intensive, are prone to operational failures or inefficiencies, or create lock-ins or pathway dependencies. It also helps to identify *'low-hanging fruits'* that can improve the system's resilience. To achieve that, the framework considers three essential aspects: (i) how

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well an option solves the problem and harnesses opportunities, (ii) how much it meets stakeholder needs, and (iii) the overall impact on the system, meaning cross-KCS implications. As a result, the framework helps reduce any biases (e.g., heuristics, confirmation, recency, status quo, sunk cost fallacy) and noises (e.g., political interests, power imbalances) that may influence the decisions and, ultimately, foster sustainable and synergistic action, underpinning systemic resilience.

An important aspect to consider in this step is an explicit link with Step 1, where decision-makers and stakeholders jointly establish the primary objective of reducing and adapting to climate-related risks and other objectives related to harnessing the opportunities that adaptation investments can bring. Another crucial consideration is the results of Step 4, where adaptation options are evaluated against their capacity to deliver MRD (accounting for co-benefits, adverse effects and trade-offs) and their viability, suitability and feasibility within a given context.

What are the required inputs?

- Results of the appraisal, including feasibility, suitability, viability, expected intervention's performance over time, full range of benefits, adverse effects, trade-offs and potentially emergent risks.
- Results of risk assessment, including ongoing and future risks, future scenarios, and uncertainties.
- Stakeholder preferences (what is relevant and to what degree).
- Other relevant criteria (e.g., costs, policy considerations, operationalisation, adoption potential, adaptability, replicability, scalability).

What are the expected outputs?

- Decision on the chosen adaptation strategy, which could be one or more interventions.

Key activities:

- Synthesize the results of the appraisal, stakeholder preferences, and policy considerations.
- Prioritise options that align with broader community goals, regulations and policies.
- Compare and, if possible, weigh the pros and cons of each option.
- Address concerns and provide a rationale for the chosen strategy.
- Select the most suitable adaptation options.
- Communicate the decision transparently to stakeholders.

Box 6. Key inputs, outputs, and activities of Step 5 'Make decision'

(6) Plan implementation.

The planning for implementation step involves developing a detailed and strategic plan that outlines specific actions, timelines, and resource allocations for putting the chosen adaptation measures into practice. Here, it is important to collaborate with various agencies and organisations to ensure a coordinated and cohesive implementation effort, as well as involving the community in the implementation process to enhance ownership and support. Planning for implementation in a rigorous, flexible and responsive fashion allow that the selected adaptation measures are executed efficiently and effectively, while preventing maladaptive outcomes.

Decision-makers can utilise the MRD framework to establish the scope and spatial influence of the intervention within the previously defined system boundaries, supporting the identification of high-priority areas that can yield the most significant returns. Doing that allows resources to be directed towards areas (i.e., leveraging points) that address multiple vulnerabilities simultaneously, resulting in interventions that not only reduce risks but enhance community well-being and unlock development potential.

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By identifying the time when different benefits and adverse effects are realised in a system, the MRD framework also helps decision-makers to set intervention timeframes which may align with the project lifecycle or more often, go beyond it. Accordingly, the framework allows decision-makers to incorporate a forward-looking perspective into the adaptation planning process, considering both short-term and long-term effects, as well as uncertainties and socio-economic trends. In doing so, the framework helps set realistic expectations and communicate them transparently to stakeholders, anticipating eventual adjustments and unforeseen consequences that may arise from the changing climate or evolving socio-economic dynamics. This proactive approach not only enhances the credibility of implemented measures and enables an adaptive management, but also aids in the identification, prioritisation, and sequencing of adaptation pathways.

The MRD framework goes beyond the scope of DRR and CCA, influencing the goal setting of the adaptation strategy (or pathway) towards more systemic outcomes such as boosting economic productivity, reducing social inequalities, and enhancing environmental sustainability while fostering a long-term view of resilience. In that sense, adaptation strategies require collaboration across different sectors and disciplines so decision-makers must engage experts from diverse fields and stakeholders from multiple sectors to create integrated plans that capitalise on the MRD concept. Accordingly, it can unlock additional financing and ensure resources through cross-sectoral projects, or multisectoral plans, and encourage decision-makers to invest in adaptation responses that create lasting positive impacts.

What are the required inputs?

- Decision document, including budgets, priorities, and relevant considerations.
- Regulatory requirements.
- Stakeholder concerns, capacities, roles and responsibilities.

What are the expected outputs?

- Comprehensive implementation plan per intervention, and overarching adaptation strategy.

Key activities:

- Develop a detailed plan that outlines specific steps, timelines, and resource allocation for implementing each of the chosen adaptation measures.
- Engage and collaborate with relevant agencies, stakeholders, and contractors to ensure a coordinated and cohesive implementation effort.
- Ensure that the plan is flexible to accommodate unforeseen challenges by incorporating adaptive management strategies.
- Plan for regular reviews and updates to the implementation plan based on monitoring and evaluation findings.
- Involve the community in the planning to enhance ownership and support of the adaptation process.
- Coordinate communication and dissemination campaigns to ensure broad understanding of the adaptation process and address any concerns.

Box 7. Key inputs, outputs, and activities of Step 6 'Plan Implementation'

(7) Implement intervention.

The implementation phase is where the planned interventions become a reality. This step involves executing the adaptation measures according to the established timeline and detailed plan. It includes the actual deployment of adaptation responses on the ground and implementing the adaptation strategy to address climate-related risks and increase resilience.

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Continuous communication with stakeholders and adaptive management are critical for promptly addressing any unforeseen challenges and ensuring the interventions' success.

The MRD framework improves the chances of successful implementation by creating a sense of ownership of the adaptation process among KCS. It encourages coordinated action between institutional agencies and concentrates multi-sectoral efforts to maximise resilience dividends. Furthermore, the framework ensures that actions align with the identified objectives and desired outcomes (in terms of resilience dividends) and prevents any foreseen adverse effects or trade-offs. Given that adaptive management is embedded in the framework, it allows adjusting the implementation based on the system's feedback and evolving circumstances regarding the intervention's impacts and ripple effects on the KCSs. This assists decision-makers in reallocating resources to yield more significant benefits, counter troubling adverse effects, or balance trade-offs across KCS. Concerning the latter, the framework helps inform decisions about the acceptability of certain trade-offs. For instance, accept inevitable trade-offs in the short term to achieve multiple dividends in the long run. In essence, the MRD framework helps direct implementation towards achieving more overarching, systemic, and impactful outcomes.

What are the required inputs?

- Implementation plan.
- Financial resources.
- Technical and human resources.

What are the expected outputs?

- Establishment and operation of the adaptation measures.

Key activities:

- Implement the adaptation measures according to the plan.
- Track the progress and performance of the implementation process to ensure it aligns with the developed plan.
- Timely address unforeseen challenges, emerging trade-offs, and unexpected adverse effects.
- Ensure effective and permanent communication with stakeholders, providing updates regularly.
- Establish mechanisms for feedback and address concerns promptly to maintain community support.
- Apply adaptive management strategies to adjust the interventions as needed.

Box 8. Key inputs, outputs, and activities of Step 7 'Implement Intervention'

(8) Monitor and evaluate.

The monitoring and evaluation stage entails a systematic assessment of the effectiveness of implemented measures over time. This allows adaptive management by reorienting implementation based on new information or changing conditions. This step is crucial for understanding whether the adaptation strategies achieve their intended outcomes. It also enables open feedback on shortcomings and emerging risks. This information is essential for learning, making informed adjustments, and continuously improving the performance of the adaptation process. Regular evaluations also help inform future decision-making and new cycles of the adaptation process.

The MRD framework is vital to building a robust and sensitive Monitor and Evaluation system. It helps to do that by following up on the realisation of benefits (intended and unintended), as well as tracking adverse effects and trade-offs. By doing so, the framework also improves the

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understanding of the intervention's performance, measuring the success of the adaptation response not only through traditional DRR/CCA indicators but also through a broader range of outcomes, such as social cohesion, economic growth, and environmental quality. This allows decision-makers to understand the intervention's impact better and encourages them to consider a more extensive range of outcomes and impacts. Hence, it helps decision-makers be more open to feedback and lessons learned and communicate changes in the intervention more transparently and accountably with the public.

Monitoring and evaluating the MRD not only identifies needs for rectification but can also detect unveiled opportunities and synergies across KCSs, informing adaptive management actions. In addition to that, MRD can help to recognise decision points for adaptation pathways by providing decision-makers with a better understanding of the adaptation choices and their various effects against the established cross-KCS goals. Overall, the MRD framework advances in gathering empirical evidence of resilience dividends for future decisions.

What are the required inputs?

- Monitoring data
- Feedback from stakeholders.
- Criteria for evaluating adaptation performance and success.

What are the expected outputs?

- Updated assessment of adaptation effectiveness.
- Recommendations for better implementation.
- Evidence for future adaptation planning cycles.

Key activities

- Establish monitoring programs to assess the effectiveness of implemented measures.
- Collect data on key indicators related to climate impacts, the performance of adaptation measures, changes in climate-related risks, and system resilience.
- Conduct periodic evaluations to assess the success of the adaptation strategy in achieving its objectives.
- Compare monitoring results with the initially identified problem, the set objectives and the evolution of risks.
- Incorporate feedback from the community and stakeholders into the evaluation process.
- Adjust the implementation plan as needed, based on changing climate patterns, new information, or detected adverse effects and trade-offs.
- Gather and share evidence and lessons learned for future decision-making.

Box 9. Key inputs, outputs, and activities of Step 8 'Monitor and Evaluate'

Table 1 provides a summary of the contribution of the MRD thinking to the decision-making process in each of its eight steps. The table highlights the role played by the MRD framework in improving the decision-making process at each step through different key points. This information can be used to not only understand the influence of the MRD on the decision-making process better, but also to its added value along the lifecycle of adaptation interventions and strategies.

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Decision-making step	MRD contributions to the decision-making process.
Identify problems and objectives.	• Turn climate risks into opportunities through multisectoral thinking and analysing overlapping priorities between KCS. • Broaden system boundaries, emphasising interconnections, synergies and trade-offs across KCS.
Assess climate risks	• A multi-dimensional analysis of climate risks and consider the risks of inaction, loss of opportunities, and maladaptation. • Understand the risk propagation across KCS and further indirect risks. • Identify additional elements that are exposed and vulnerable to hazards. • Provide insights for future adaptation needs, adaptation limits, and residual risks.
Identify adaptation options	• Widen the range of adaptation options based on synergies across KCS. • Identify interconnected, bundled, and multi-functional responses addressing direct, indirect, cascading, and future risks. • Broad the range of involved stakeholders.
Appraise adaptation options	• Prioritise systemic adaptation over those options working in isolation. • Quantitatively and qualitatively evaluate options against overlapping, cross-cutting, and multisectoral priorities and objectives beyond DRR/CCA. • Appraise options comprehensively, considering their full spectrum of benefits and adverse effects, including potential trade-offs, conflicts, and maladaptation risks. • Compare options and determine 'what', 'how much' and 'when' benefits will be delivered, evaluating the performance and overall resilience gains of the option under different climate scenarios, as well as their contribution to the system's transformation. • Integrate stakeholder perceptions and priorities ('what' benefits are relevant and 'to what' degree) to examine the appropriateness of adaptation options given the local conditions and dynamics. • Map specific communities, KCS, or areas where adaptation options are more appropriate to implement, considering both the local biophysical and climatological characteristics, as well as the socio-economic and cultural aspects. • Identify enabling environment and implementation challenges for each adaptation option to select responses that can work efficiently and sustainably in the long run.
Make decision	• Select "*low-regret*" options and "*low-hanging fruits*" to lever systemic resilience. • Prioritise options based on (i) how well it solves the problem and harnesses opportunities, (ii) how much it meets stakeholder needs, and (iii) the overall impact on the system, meaning cross-KCS implications. • Reduces influential decision-related biases and noises.
Plan implementation	• Define timeframes, spatial scale, and high-priority areas where investment can yield the most significant returns. • Aid in the identification, prioritisation, and sequencing of adaptation pathways. • Set more systemic goals and expected outcomes beyond the scope of DRR and CCA and integrate a long-term view of resilience. • Promote cross-sectoral (i.e., cross-KCS) alignment, multisectoral actions, and interdisciplinary and inter-agency collaboration. • Unlock additional financing and ensure resources through integrated KCS planning.
Implementation intervention	• Improves the chances of successful intervention by fostering ownership among the KCS. • Coordinate actions between agencies and concentrate multisectoral efforts to maximise resilience dividends. • Prevent any foreseen adverse effects and balance trade-offs. • Reallocate resources to achieve more significant benefits. • Accept trade-offs in the short term to achieve multiple dividends in the long run. • Direct implementation towards achieving more systemic and impactful outcomes.
Monitor and evaluate	• Build a robust and sensitive M&E system. • Improve the understanding of the intervention's performance. • Measure the intervention's success beyond the DRR/CCA outcomes, independent of a disaster event. • Encourage multi-faceted and more open feedback. • Build transparency and accountability when making management decisions. • Help informing decision points for adaptation pathways. • Gather thorough empirical evidence of interventions for future decisions.

Table 1. Key contributions of the MRD concept to enhance the decision-making process.

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4.2.2 Choices: a balance between robustness, relevance and resources.

When making decisions, it's important to consider three key factors: Robustness, Relevance, and Resources (IPBES, 2022). At each step of the decision-making process, choices must be made based on a thorough analysis of the available options and in alignment with the goals and decision-making context, using all local capacities efficiently. In every case, decision-making and its outcomes must ensure: (i) robustness by using reliable methods, consistent evidence, and achieving wide social acceptance.; (ii) relevance by taking into account all different needs, perspectives, and priorities; and (iii) resources by considering requirements and constraints, in terms of time, finances, technical, and human resources.

4.2.3 Participation: Continuous stakeholder and multi-sectoral engagement, Communication, and Learning.

Continuous stakeholder and multi-sectoral engagement are integral components of the MRD framework. The framework seeks to actively involve diverse stakeholders in decision-making processes, ensuring that various perspectives are considered. To facilitate that, clear and accessible communication of information, methodologies, and results is fundamental. This enables stakeholders to realise the reasoning behind decisions and contributes to a shared understanding of the adaptation options. Continuous engagement and communication with stakeholders allow decision-makers to learn from previous experiences, both successes and challenges, as well as from the current implementation (e.g., unintended benefits, unforeseen adverse effects, emerging trade-offs and risks, unveiled synergies). Moreover, ongoing learning helps refine choices in each step of the decision-making cycle, gradually leading to more effective and informed adaptation strategies.

Notably, continuous stakeholder and multi-sectoral engagement, communication, and learning are cross-cutting practices of the MRD framework. These practices aim to empower stakeholders, foster ownership of the adaptation process, build trust and legitimacy in decisions, and encourage partnerships and collaboration between different actors. Ultimately, this helps to enable a long-term vision of resilience-building and climate adaptation.

4.2.4 Approaches: Adaptive Management, Systems Thinking and Complexity

Adaptive management, Systems Thinking and Complexity are woven into the fabric of the MRD framework, reflecting its dynamic and responsive nature in the face of complex challenges. The framework is iterative, allowing for ongoing adjustments and refinements in the decision-making process based on feedback from implementation, emerging challenges, and evolving circumstances. Additionally, the MRD framework is rooted in systems thinking, which provides a comprehensive understanding of resilience-building and the interconnectedness of systems. The framework emphasises that resilience is not a singular outcome but a dynamic process embedded within the development of larger systems. Under the MRD framework, intervention benefits cascade in different forms, mechanisms, and channels across sectors, scales, and spaces, incorporating the interconnectedness of systems in decision-making. This understanding allows for a thorough examination of adaptation responses, underscoring that a change in one area can have ripple effects throughout the entire system (or across systems), which aligns with the core tenets of systems thinking. The MRD framework integrates complexity by considering adaptation benefits as a continuum, with multifaceted benefits unfolding at different periods and varying subjectively based on the recipient. At its core, the MRD framework encourages adaptation strategies that address

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the complex nature of climate change challenges by considering KCS interactions and interdependencies.

4.3 An illustrative example of the MRD framework application

Identifying the problem and objectives: In a coastal city, the problem could be increased flooding due to rising sea levels. Here, the concerns and priorities of fishermen, residents and firms located on the shoreline are notably important, besides the perspectives of NGOs, academic institutions, and local authorities. Also, regulatory constraints on coastal management, budget limitations, potential conflicts with existing land-use policies, and uncertainties in future sea-level rise projections are important aspects that need to be identified from the beginning of the decision-making cycle. Furthermore, acknowledging that the impacts of rising sea levels may unfold over several decades, the decision-making process should consider different timeframes to include immediate and long-term adaptation strategies (e.g., by 2030, 2050, 2080). Taking all of that into consideration, authorities and stakeholders agree that the objective is to protect critical infrastructure and enhance community resilience by 2080.

Assessing climate risks: This step implies modelling multiple future sea-level rise scenarios to understand different levels of increased flooding in the coastal city. To do that, scenarios can be modelled using different levels of greenhouse gas emissions and socio-economic development (e.g., population growth, urbanisation, income) at multiple timeframes. This will help determine which areas are at high risk of sea-level rise, increased flooding as well as other effects like saltwater intrusion, land salinisation, and coastal erosion. Analysis reveals that the city's critical infrastructure, such as roads and water treatment plants, is vulnerable to increased flooding, while other sectors, such as agriculture, water security, and transport, may be indirectly affected. Moreover, disruptions in these sectors may have cascading effects on, among others, education and public health due to inaccessibility to schools or the increase in vector-borne diseases.

Identifying adaptation options: In this step, various stakeholders, such as fishermen, engineers, urban planners, tourism sector representatives, and local community leaders, work together to explore the diverse needs, perspectives, and experiences to propose various adaptation options. Some of these options may include constructing sea walls, implementing zoning regulations to control development in vulnerable areas, establishing early warning systems, promoting saline-resistant crops, and promoting sustainable and restorative use of ecosystems.

Appraising adaptation options: Using multi-criteria analysis, decision-makers in the coastal city evaluate the overall resilience dividends that the identified options can eventually deliver in different timeframes and to different KCS. This assessment of adaptation viability is centred not only on CCA and DRR aspects but also on the additional implications (cascading effects, synergies and trade-offs) to other societal goals, such as poverty alleviation and food security. Besides the effectiveness, other technical (e.g., operation, endurance, potential risk reduction), environmental (e.g., impacts on local ecosystems or water quality), political (e.g., alignment with policies) and social (e.g., acceptance, cultural coherence) factors are also included in the feasibility assessment of the option. This provides a better understanding of the existing conditions favouring or hindering the implementation of each adaptation option. Additionally, to appraise each option, it is important to collect the diverse perspectives of all stakeholders involved, both positive and negative. This part of the process also involves identifying context-specific aspects, such as biophysical (e.g., existing ecosystems, coastal erosion patterns, relief), climatological (e.g., rate of sea level rise, frequency of storm surges),

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socio-economic (e.g., economic sectors potentially impacted, potential displacement and relocation of vulnerable communities, critical infrastructure at risk), and cultural elements (e.g., cultural heritage sites, traditions tied to the shoreline, recreational and aesthetic value of the coastline) that may have an impact on the performance of a given option. By considering the preferences and concerns of stakeholders, as well as key contextual characteristics, decision-makers can have a better sense of which adaptation options are more suitable for the local conditions. This ensures that the selected options are aligned with the specific needs and requirements of the affected stakeholders and are, therefore, more likely to achieve the desired outcomes. As a result of this comprehensive appraisal, some of these options are filtered out due to high costs, low effectiveness, desirability or capacity to deliver resilience dividends (e.g., constructing sea walls, promoting saline-resistant crops) while ranking the pre-selected ones (e.g., 1-promoting sustainable and restorative use of ecosystems; 2-implementing zoning regulations to control development in vulnerable areas, and 3-establishing early warning systems).

Making decisions: After considering public input, socio-economic analyses, and environmental impacts of each adaptation option, decision-makers decide to invest in a portfolio of interventions (*more information in Deliverable 6.3)*. This portfolio -or adaptation package- consists of a combination of sustainable land-use planning, and "green" infrastructure (e.g., restoration of mangroves and tidal marshes). To do so, they integrate information on the costs, adaptation benefits, stakeholder preferences, and potential synergies (i.e., additional benefits) with other societal goals (e.g., economic development, social well-being, food security, water security). Decision-makers also carefully weigh the advantages and disadvantages, including trade-offs, to make a balanced decision. Furthermore, they verify that the adaptation measures have a high acceptance -particularly by the vulnerable communities- and are aligned with national and regional policies on sustainable development. Considering how the selected options can contribute not only to addressing the risk of sea-level rise in the short- and long-term but also to the overall well-being and systemic resilience of the community, the decision is communicated transparently through community meetings, public forums, and public reports. This approach ensures that stakeholders are well-informed and their concerns about the adequacy of the selected adaptation options are addressed properly.

Planning the intervention: Decision-makers and adaptation planners develop an overarching adaptation strategy *(i.e., adaptation pathways—more information in Deliverable 6.2). This strategy* explains how the adaptation measures will work together in a harmonic and targeted way and how risks will be effectively managed under uncertain conditions via adaptive management. Given the knowledge gained from each adaptation option during the appraisal, it is possible to understand *'what'* benefits they offer, *'how much'* they deliver, and *'when'* these benefits are realised, helping in the sequencing and timing of actions. Based on this and other relevant information, the adaptation strategy outlines possible future scenarios, maps various sequences of actions (*'trajectories'*) and their interdependencies, describes *'dynamic timelines'* that can be adjusted over time in response to new information and changing conditions, and establishes decision points (*'triggers'*) that would prompt a review or change in the adaptation strategy. Regular consultation meetings are conducted with contractors, local authorities, sectoral representatives, and community leaders to co-develop the adaptation strategy, as well as build ownership.

In addition to the strategy, the adaptation portfolio describes each intervention in detail. For the coastal city, such portfolio description includes relevant aspects such as landscape design,

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technical requirements, and budget for restoring coastal ecosystems, and coordination activities with firms, governmental bodies, and other sectoral representatives to co-delineate zoning regulations and update the regional land-use plan. Furthermore, given that selected measures synergise with many sectors, decision-makers and adaptation planners persuade the private sector to invest in these options through different finance instruments and products (*more information in the WP5 deliverables)*, making a large-scale and long-term adaptation process possible.

Once the adaptation plan, including the adaptation pathway, portfolio, and associated finance instruments, is completed, it is shared with the public and disseminated with relevant stakeholders.

Implementing the interventions: this step refers to the phase in which the implementers, in collaboration with communities and NGOs, undertake the ecosystem restoration activities such as site preparation, tree planting, fencing, and controlling invasive species. Also, implementers, together with governmental agencies, urban planners, and sectoral representatives, conduct institutional actions such as dissemination and raising awareness campaigns to establish and enforce the new zoning regulations.

Monitoring and evaluating: In this step, adaptation implementers and decision-makers in the coastal city monitor the effectiveness of the restoration efforts and the introduced zoning regulations in reducing flood damages due to sea-level rise, as well as other realised benefits or adverse effects derived from the interventions. They also track changes in flood frequency and severity and new social behavioural patterns that demand adjustments to the initial adaptation strategy, including complementary interventions like upgrading early warning systems, relocating some communities, or elevating some buildings. The results of regular evaluations are then communicated and shared with the local community, sectoral representatives, and other relevant regional stakeholders.

4.4 Tools and methods to characterise the Multiple Resilience Dividends

The concept of Resilience Dividends holds great potential for decision-making, but a large difficulty at the moment is their characterisation, which hinders its wide practical application (Rözer *et al.*, 2023). However, several tools and methods in the context of adaptation and resilience can be adapted to examine resilience dividends. The most conventional methods include cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and multi-criteria analysis (MCA) (Mechler and Hochrainer-Stigler, 2019). Also, more advanced tools like robust decision-making (RDM) have recently been utilised (Doeffinger and Rubinyi, 2023). Additionally, hybrid approaches combining two or more methods have been used for more comprehensive analysis despite increased practical complexity. For instance, Higuera Roa *et al.* (2023) combined MCA, Geographical Information System (GIS), and multi-stakeholder engagement to build adaptation packages of nature-based solutions, delivering multiple benefits besides adaptation and risk reduction. Another example is the integrated framework developed by Grafakos, Gianoli and Tsatsou (2016) called the Sustainability and Resilience Benefits Assessment (SRBA). It uses scenario planning to set a baseline scenario to help determine the types and levels of benefits a project can deliver in a successful scenario. The framework uses a combination of bottom-up and top-down procedures, including stakeholder engagement, multi-criteria analysis, and GIS data application, to estimate the expected benefits.

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The subsequent sub-sections will provide an overview of a diverse range of methods and tools. These methods vary in complexity and orientation, from expert-centred to participatory approaches. Additional methods are presented in Annex 3- *Other methods and techniques to characterise resilience dividends.*

4.4.1 Cost-Benefit Analysis

Purpose	Challenge	Application
Compare options (costs and benefits) in monetary terms	Quantification of intangibles; dealing with uncertainty; data availability.	Public investments, particularly large-scale infrastructure projects.

CBA is a standard economic tool used to evaluate different intervention options with the goal of selecting the most economically efficient option (Watkiss *et al.*, 2015; Doeffinger and Rubinyi, 2023). It provides a structured approach to assess all the relevant costs and benefits of each alternative, using money as a common measure (Watkiss *et al.*, 2015; Mechler and Hochrainer-Stigler, 2019). Based on this, it is possible to compute the Return on Investment (ROI), Internal Rate of Return (IRR), Net Present Value (NPV), and Payback Period of a specific intervention (Abanda *et al.*, 2022). That is why CBA is particularly important in the public sector as it ensures effective resource allocation within budget constraints (Markanday, Galarraga and Markandya, 2019).

CBA can be applied to a wide range of climate resilience actions, including projects, programs, and policies (Heubaum *et al.*, 2022). It compares options by calculating benefit-cost ratios (Figure 8), which is the total discounted benefits minus the total discounted costs (Watkiss *et al.*, 2015), as well as other indicators such as ROI, IRR, and NPV. While CBA can estimate the most common resilience benefits (e.g., infrastructure damage, displacement, loss of function, economic disruptions) (Keefe, 2018), it also encourages incorporating co-benefits into the analysis (Helgeson and O'Fallon, 2021).

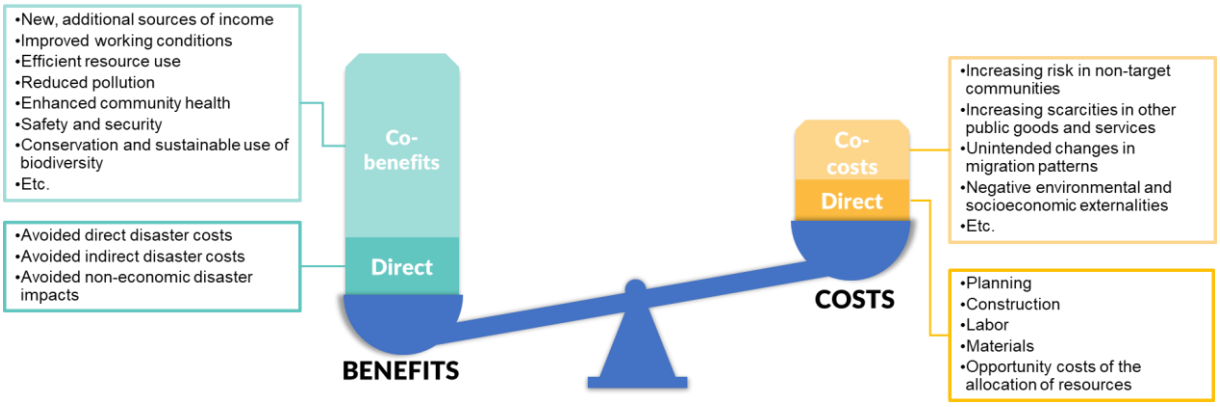

Figure 8. Representation of the CBA core analytical principle (based on Vorhies and Wilkinson, 2016)

Because CBA results are easy to communicate and understand, it can reach to a broad audience, especially those involved in public resilience investments (Keefe, 2018; Markanday, Galarraga and Markandya, 2019). It is commonly used for large-scale infrastructure projects with significant economic benefits (e.g., hard flood risk prevention projects) (Mechler and Hochrainer-Stigler, 2019; Doeffinger and Rubinyi, 2023) but less frequently for "soft" interventions (Watkiss *et al.*, 2015; Mechler and Hochrainer-Stigler, 2019).

However, CBA faces several challenges when applied to resilience interventions. These challenges include issues related to timescales, discount rates, future scenarios, uncertainties,

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and low-probability, high-impact risks (Markanday, Galarraga and Markandya, 2019). Additionally, expressing all analysis variables in monetary terms makes it difficult to capture the values of intangible and non-market aspects like health, environmental quality, social cohesion and well-being (Watkiss *et al.*, 2015; Francis Vorhies and Wilkinson, 2016; Fung and Helgeson, 2017; Keefe, 2018; Markanday, Galarraga and Markandya, 2019; Mechler and Hochrainer-Stigler, 2019; Abanda *et al.*, 2022). Also, analysts and decision-makers often impose assumptions on CBA, leading to misleading results, especially when dealing with uncertain risk probabilities and costs/benefits (Watkiss *et al.*, 2015; Keefe, 2018). It often does not account for risk preferences or uncertainty aversion (Watkiss *et al.*, 2015) and may miss factors like distributional effects, intergenerational equity, environmental justice, tipping points, and intervention effectiveness (Markanday, Galarraga and Markandya, 2019), which are essential in the context of a rapidly changing climate.

4.4.2 Cost-Effective Analysis

Purpose	Challenge	Application
Compare performances of interventions in achieving a set goal.	Agreeing on a single objective, relying on a single metric, and difficulty in accurately gauging effectiveness due to differing perceptions of benefits over time.	Policy, programs, and projects at different levels; mainly for technical solutions.

Cost-Effective Analysis (CEA) is a method used to compare the costs of different interventions in achieving a similar outcome (Watkiss *et al.*, 2015). It avoids the need to assign monetary values to intangible benefits (e.g., saving lives and ensuring livelihoods), making it easier to assess various resilience options once a specific goal (e.g., reduce risk and vulnerability to climate change, strengthen resilience and enhance adaptive capacity, enhance well-being and sustainable development) is set (Watkiss *et al.*, 2015; Mechler and Hochrainer-Stigler, 2019).

CEA ranks adaption options by comparing their cost-effectiveness, which is the cost per unit of delivered benefits (Watkiss *et al.*, 2015). This allows decision-makers to either find the least cost solution to achieve pre-established targets or identify the option that maximises benefits within available resources (Watkiss *et al.*, 2015; Mechler and Hochrainer-Stigler, 2019).

CEA can work at different levels, such as policy, program, or project (Mechler and Hochrainer-Stigler, 2019), and is especially useful in environmental policy evaluation and situations where assigning monetary values to benefits is challenging (Watkiss *et al.*, 2015). It's more commonly used for technical solutions than softer interventions, as technical benefits are easier to quantify (Watkiss *et al.*, 2015; Mechler and Hochrainer-Stigler, 2019).

However, CEA applications in adaptation contexts are rare and face several challenges (Watkiss *et al.*, 2015). Firstly, defining and agreeing on a single objective can be challenging (Mechler and Hochrainer-Stigler, 2019). Secondly, since CEA relies on a single metric that may not assess options comprehensively, it may not capture all benefits (Watkiss *et al.*, 2015). Lastly, the perception of benefits can vary over time, location, and among different groups, making it difficult to gauge effectiveness accurately (Watkiss *et al.*, 2015; Fung and Helgeson, 2017).

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4.4.3 Multi-Criteria Analysis

Purpose	Challenge	Application
Evaluate effects quantitatively, qualitatively or both, and compare interventions' performance and trade-offs against multiple goals, depending on the context and local priorities.	Selection of the appropriate MCA technique; time-consuming	Complex situations with competing objectives and conflicting considerations and outcomes

Multi-Criteria Analysis (also referred to as Multi-Criteria Decision-Making (MCDM) and Multi-Criteria Decision Analysis (MCDA) in the literature) is one systematic way to make sense of the wide range of information that may be relevant to making resilience-related choices with multiple competing or complementary objectives (Dixit and McGray, 2013; Alves, Gersonius, *et al.*, 2018; Cohen *et al.*, 2019; Abdullah, Siraj and Hodgett, 2021; Abanda *et al.*, 2022). It provides a structured approach to decision-making by enabling the comparison among a set of defined options across diverse criteria (e.g., efficiency, costs, performance, equity) with different ranges of convergence of priorities and values (Dixit and McGray, 2013; Adem Esmail and Geneletti, 2018; Alves, Gersonius, *et al.*, 2018; Cohen *et al.*, 2019). It decomposes complex problems into smaller components of divergent, independent, and relevant values and priorities (Dixit and McGray, 2013; Fung and Helgeson, 2017; Alves, Gersonius, *et al.*, 2018; Jia, Chen and Du, 2021).

Rather than a unique procedure or collection of techniques, MCA is a framework for thinking (Cohen *et al.*, 2019). Multiple methods exist for conducting an MCA (Figure 9). Some methods rely on stakeholder engagement, while others are more deliberative processes; some integrate complex numerical computation, while others are more qualitative-oriented; some identify an optimal option, while others rank options or may result in acceptable and unacceptable options (Dixit and McGray, 2013; Cohen *et al.*, 2019; Lindfors, 2021). MCA has been designed to address four types of problems: 1) The choice problem, in which MCA is used to select the best option from a set of alternatives; 2) The sorting problem, in which MCA is used to assign a set of alternatives to predetermined categories; 3) The ranking problem, in which MCA is used to order the alternatives partially or completely, and 4) The description problem, in which MCA is used to define alternatives, construct a set of criteria, and determine all or some alternatives' performance for the criteria, considering additional information (Abdullah, Siraj and Hodgett, 2021).

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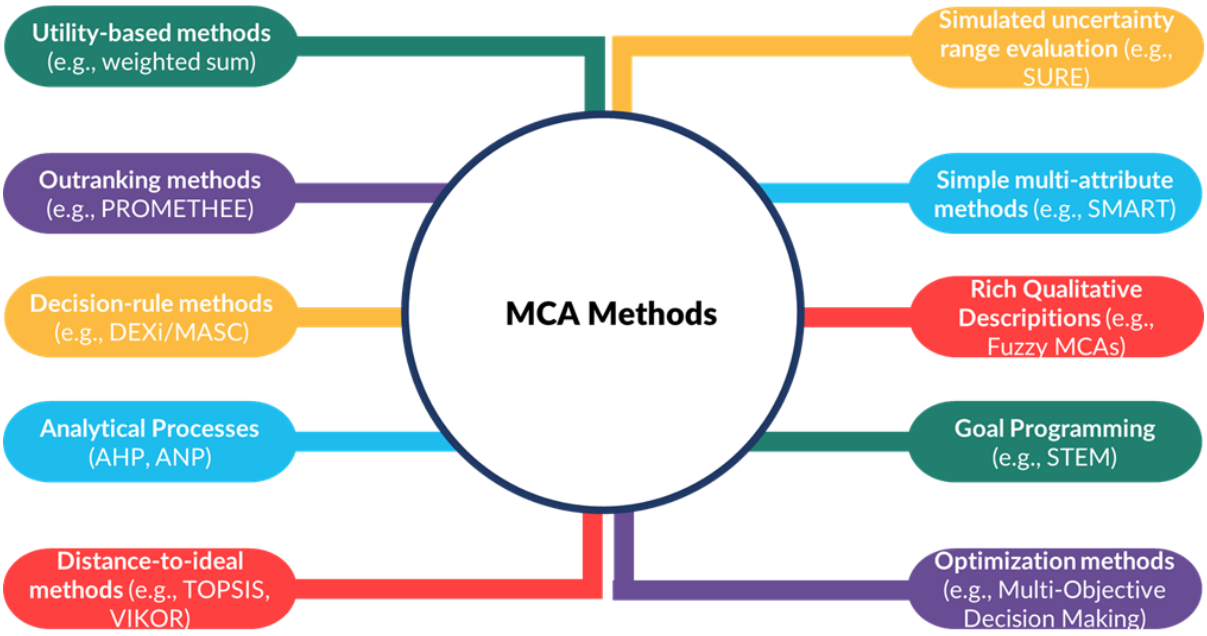

Figure 9. Categorisation of different MCA methods (based on Abdullah, Siraj and Hodgett, 2021; Lindfors, 2021)

It is considered an effective, robust, powerful and flexible decision-making approach (Adem Esmail and Geneletti, 2018; Alves, Gersonius, *et al.*, 2018; Cohen *et al.*, 2019; Abdullah, Siraj and Hodgett, 2021; Jia, Chen and Du, 2021; Abanda *et al.*, 2022). MCA facilitates the communication of the decision elements to the public while allowing outsiders to track the decision-making process (Dixit and McGray, 2013). Principally, MCA methodologies provide the multi-dimensionality aspect employed to handle a decision with independent criteria (Lindfors, 2021), while allowing trace trade-offs and conflicts between socio-political, environmental, and economic factors (Abanda *et al.*, 2022). A key strength of MCA is that it allows the integration of quantitative and qualitative data in different forms, formats or quality, as well as stakeholder preferences and political priorities (Dixit and McGray, 2013; Adem Esmail and Geneletti, 2018). By doing that, MCA fosters transparency and fairness and builds legitimacy for decisions (Dixit and McGray, 2013). To enhance results reliability, MCA can be supported by other tools, such as sensitivity analysis, geographical information systems, Delphi technique, and focus groups (Adem Esmail and Geneletti, 2018; Cohen *et al.*, 2019). Overall, MCA is well-suited to gather a full picture of the costs (i.e., cons) and benefits (i.e., pros) of the assessed options in different sectors and at various governance levels (Dixit and McGray, 2013; Adem Esmail and Geneletti, 2018; Alves, Gersonius, *et al.*, 2018).

MCA allows for a mix of monetary and non-monetary information, as well as the integration of intangible impacts (e.g., on environmental quality, equity, and social cohesion) if they are identified as important by stakeholders (Dixit and McGray, 2013; Mechler and Hochrainer-Stigler, 2019). For decision-making, the MCA can provide a more user-oriented analysis to compare and evaluate the effects of different intervention options (e.g., sea-walls vs. relocation vs. ecosystem-based measures for rising sea levels) and their compatibility with other socio-economic and environmental goals (Cohen *et al.*, 2019; Heubaum *et al.*, 2022).

However, if it is poorly designed, MCA may leave out important criteria, hide trade-offs and overlook synergies, which can influence participants towards a specific decision (Dixit and McGray, 2013; Cohen *et al.*, 2019). On the other hand, MCA can become technically challenging when numerous criteria are included in the analysis, making it difficult to reach a

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consensus among analysts (Adem Esmail and Geneletti, 2018; Abanda *et al.*, 2022). Additionally, when information is not equally accessible (i.e., language, format, communication channels, details, and topics) to all participants (e.g., experts, stakeholders, and community representatives), it may create power imbalances, which could be detrimental to the process (Dixit and McGray, 2013; Cohen *et al.*, 2019). Moreover, the credibility, usefulness, and confirmability of MCA's results may be undermined when methods, alternatives, criteria, and indicators are not well described (Lindfors, 2021). As such, it is imperative that MCA be designed and implemented with due diligence to ensure its effectiveness in decision-making.

MCA is widely used in various decision contexts, particularly when there is a need to decide between two or more options, when multiple and conflicting criteria need to be considered, and when complex settings with multiple stakeholders involved (Dixit and McGray, 2013; Fung and Helgeson, 2017; Abdullah, Siraj and Hodgett, 2021). For example, various literature reviews have shown that MCA has been applied in the prioritisation of infrastructure projects (World Bank, 2021), climate mitigation (Cohen *et al.*, 2019; Abanda *et al.*, 2022), sustainability assessment (Lindfors, 2021), nature conservation (Adem Esmail and Geneletti, 2018), and in DRR and CCA (Dixit and McGray, 2013; Alves, Gersonius, *et al.*, 2018; Abdullah, Siraj and Hodgett, 2021)

4.4.4 Robust Decision-Making

Purpose	Challenge	Application
Addressing uncertainty and robustness	Computational knowledge required; choice of parameters and trade-offs	Long-term projects involving uncertainties

A decision-support tool gaining more attention in the adaptation assessment field dealing with uncertainty is *Robust Decision-Making* (RDM) (e.g., Watkiss *et al.*, 2015; Kwakkel, Haasnoot and Walker, 2016).

Robust decision-making is a decision-support tool focusing on robustness instead of economic viability (Watkiss *et al.*, 2015). By applying a *"(…) set of concepts, processes, and enabling tools that use computation*" (Lempert, 2019, p. 23), it is possible to generate an ideal outcome of "*policy-relevant scenarios and robust adaptive strategies*" (ibid.). For this, selected strategies are iteratively (stress-)tested on multiple future scenarios (Watkiss *et al.*, 2015).

The choice of parameters and trade-offs for the scenarios is a critical step for applying the tool (Watkiss *et al.*, 2015), which requires knowledge of the system. However, handling the input of qualitative and quantitative data to generate a multitude of scenarios also demands a certain level of technical skills (Mechler and Hochrainer-Stigler, 2019). This can pose a significant bottleneck for regional applications with often less expert end-users.

RDM is not restricted to decision-making in a climate change adaptation context, however, its approach allows to minimise regrets or include 'no-regret'[8]/'low-regret', reversible or flexible strategies with a climate change focus (World Bank, 2021; New *et al.*, 2022). 'Low-regret' options are especially important for decision-making under uncertainty as they include co-benefits under alternative futures, thus bridging the gap towards (transformative) adaptation.

[8] The term "no-regret" options has been recently debated. While the consulted literature uses this term, it is recommended to use the notion of "low-regret" as every adaptation option comes with a trade-off.

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Regarding climate change, it's hard to predict what will happen and how we should adapt to it. That is why it is important to consider uncertainty when deciding. In addition to tools that focus on quantification, it's also important to consider the possibility of unexpected events and outcomes. Hence, embracing uncertainty can add a valuable perspective for accounting resilience dividends. However, this approach comes with rather limited practicability of dividend quantification and instead explores possibilities of assessing dividends qualitatively.

There are alternative methods to deal with the challenges of climate change uncertainty that do not rely on probabilities. These methods involve exploring various scenarios or adapting to multiple options. Some examples of such approaches include *Adaptation Pathways* (e.g., Haasnoot *et al.*, 2012; Fung and Helgeson, 2017), *Dynamic Adaptive Planning (DAP)* (e.g. Walker, Marchau and Kwakkel, 2019), *Info-Gap Decision Theory (IG)* (e.g. Ben-Haim, 2019), *Dynamic Adaptive Policy Pathways (DAPP)* (e.g., Kwakkel, Haasnoot and Walker, 2016) or *Engineering Options Analysis* (e.g. De Neufville and Smet, 2019).

4.4.5 Narratives

Purpose	Challenge	Application
Integrate bottom-up perspectives and context specificities in the assessment of resilience dividends	Subjectivity bias and limited generalizability.	Bottom-up; qualitative assessment

Narratives add to the group of approaches that allow for qualitative assessment of resilience dividends. Resilience analyses based on this approach involve a variety of audiences and combine heterogenous "*information, people, actions and consequences*" (Helgeson and O'Fallon, 2021, p. 3), thus fostering a bottom-up perspective and application. Narrative-based approaches can be utilized alone or in combination with other tools, particularly when dealing with limited quantitative data, capturing intangible benefits, or building consensus and shared understanding.

Establishing a narrative approach that includes categorising resilience dividends can help communities recognise the additional benefits of adaptation measures. The emotional and more appealing aspect of narratives compared to quantitative data and models has the potential to significantly shape the discourse (Chapman, Lickel and Markowitz, 2017; Helgeson and O'Fallon, 2021) for involved stakeholders, decision-makers or the community itself.

However, these advantages come with a downside: the difficulty of quantifying resilience dividends or making objective statements gives the narrative approach limited power reflected in its application. Only a few publications assess resilience dividends within narratives such as 'transformative win-win narratives' described by Hinkel *et al.* (2020).

4.4.6 Selecting the right way to characterise MRD

Given the diversity of decision needs, there are different options to evaluate the capacity of adaptation options to deliver MRD (Figure 10). Depending on the local realities (social, economic, cultural, technological, environmental, and institutional aspects), particular evaluation methods are more suitable than others. The choice of a specific evaluation method, technique or tool will primarily depend on the relevance (i.e., salience in terms of the outputs that can be used in decisions), robustness (i.e., reliable, consistent and socially representative) and resource requirements (i.e., time, financial, technical and human resources) of each method. Regardless of the evaluation method used, all of them consider possible benefits and adverse effects (also known as costs), only differing in how information is incorporated into

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the evaluation (qualitatively, quantitatively, or a mix) (Doeffinger and Rubinyi, 2023). Thus, the MRD framework does not follow a one-size-fits-all approach.

While CBA has traditionally been used to evaluate resilience dividends, other approaches such as MCA, CEA, and RDM offer additional perspectives to assess different benefits and trade-offs of investing in resilience (Mechler and Hochrainer-Stigler, 2019; Heubaum *et al.*, 2022). CEA, for example, can help compare the costs required to achieve a desired outcome and simplify the selection process by choosing the intervention that achieves the desired outcome with fewer costs or the intervention that delivers more benefits within a fixed budget. MCA, on the other hand, can consider multiple criteria beyond just resilience, including social, environmental, and economic goals, leading to a more comprehensive understanding of resilience outcomes across different arenas. Finally, RDM offers an adaptive approach to decision-making under deep uncertainty by assessing the resilience of different strategies across multiple future scenarios.

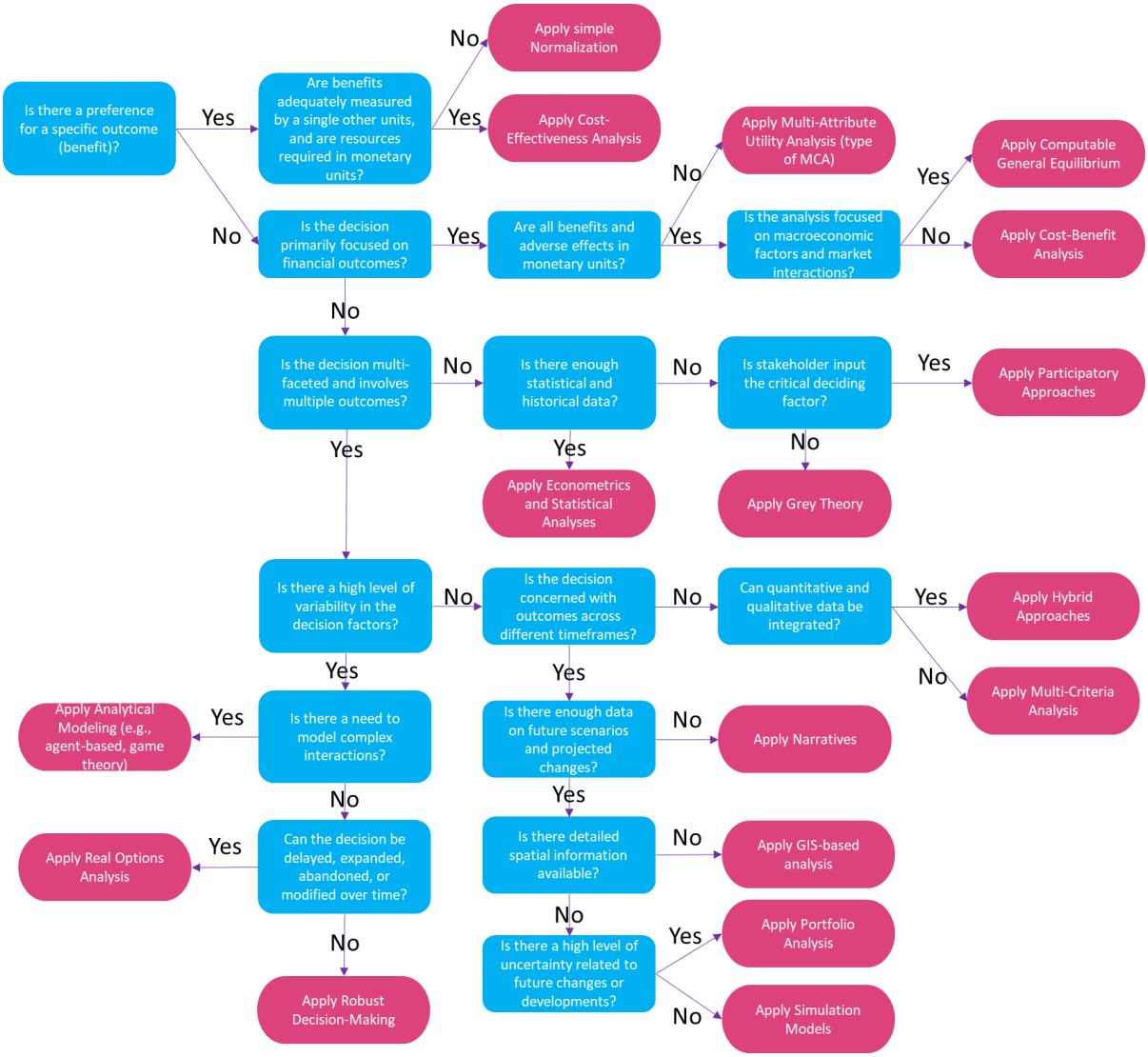

Figure 10. Decision tree of different methods to characterise resilience dividends.

The navigation of the decision tree will be expanded in Deliverable 6.3 (D6.3) - "*Technical guidance and capability development modules on frameworks/methods*". It is worth noting that

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there are no ''one-size-fits-all'' solutions when selecting a method to characterise dividends, as this will be heavily influenced by a local context (e.g., data availability, capacity of personnel leading the characterisation). However, the applicability of the MRD framework for appraising and selecting adaptation options through MCA as one of several tools and methods delineated in the decision tree and in this section will be described in finer detail in D6.3. Additionally, training materials that explain the practical application of the MRD framework will be created within Task 7.1 "*Capacity building execution and implementation*".

5 Implications of the Decision Framework for P2R

Regions supported through P2R will be offered a plethora of tools, methods, and services to support and guide them in their transition towards a resilient future. In this context, different work packages are developing different tools, methods and services which aim to be mutually reinforcing, ultimately supporting regions in the RRJ. In this section, we discuss how the MRD framework developed in this work supports some of the crucial deliverables of P2R project.

5.1 Integrating the Decision Framework into the Regional Resilience Journey

The MRD framework presented in this report is not a distinct approach from the RRJ, but rather an integral part of its thinking, as these two frameworks are mutually reinforcing. In the original description of the guide to the RRJ (*see* Deliverable 4.1*),* there is an explicit reference to MRD under the pathway definition section. The RRJ guidance indicates that the identification and assessment of adaptation options includes assessing these options against their capacity to deliver MRD, as well as scrutinising real-world impacts on ecological, social, and economic domains, and possible synergies with other societal goals. Assessing adaptation options against MRD is important for building a broader value proposition of adaptation options (i.e., business case).

While the explicit reference to MRD was made in the description of RRJ, in this section, we identify further areas where MRD inform and is synergic with RRJ. Figure 11 summarises key points of the MRD framework that can support the RRJ (*green tick marks*), highlighting the aspects in which it plays a significant role (*dotted outline in orange*), and particularly its contribution to the co-designing portfolio of interventions step (*solid outline in purple—see* Section 5.2).

As Figure 11 depicts, a clear synergy between MRD and RRJ can be found in almost all of the steps of the RRJ. This alignment comes through both RRJ and MRD being based on systemic thinking, emphasising the need for multi-sectoral, cross-scalar, and transformative adaptation pathways and resilience building, which will serve multiple goals and objectives. It is therefore important to emphasise that RRJ and the MRD are not two separate and competing frameworks, but rather, one could see the MRD framework and the ''co-benefits'' lens it introduces as a contributor to RRJ implementation. For instance, as the framework is accompanied by an overview of an array of methods to characterise the MRD (Section 4.4), these could be useful for regions while implementing the RRJ in the context of broader support provided to the regions by WP6.

As explained throughout this report, the MRD thinking offers an alternative to traditional appraisal of adaptation options, including often single-sector approaches that do not consider wider system interdependencies (i.e., synergies and trade-offs between different sectors), thus failing to benefit from existing opportunities and to deliver systems change needed to

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tackle the scale of the issue at hand. By shifting the adaptation decision-making towards a process that explicitly characterises and promotes the multiple dividends of resilience, the MRD framework provides an opportunity to inform the building of shared vision in RRJ by exploring alternative futures. For instance, the value-led choices to be made by regions will differ by what type of adaptation co-benefits are of interest to the local stakeholders (e.g., differences occur if driven by economic vs social vs environmental outcomes). Therefore, by embracing the MRD concept, regions are opened to a greater understanding of possible futures based on the options they choose. They begin to realise that there are multiple paths leading to different outcomes, each with unique possibilities to consider. This knowledge empowers them to make informed decisions and steers their journeys towards system transformation.

It is also important to emphasise that the application of the MRD framework in practice relies on the same set of enabling conditions needed for the RRJ: i) finance and resources, ii) knowledge and data, iii) governance, engagement and collaboration, iv) capabilities and skills, v) behavioural change, and vi) experimentation, learning, and reflection. However, applying the MRD thinking in practice can also serve as a powerful enabler in the adaptation processes. For example, it involves aligning financial streams and cross-sectoral budget planning, generating knowledge and data on the performance of adaptation responses, informing learning and reflection through monitoring and evaluation, establishing governance structures and processes that foster cross-sectoral cooperation, and building regional capacity for a comprehensive appraisal of adaptation options. Thus, adopting the MRD framework along the Journey's decision-making is crucial for regions to foster transformational adaptation and build systemic resilience more effectively.

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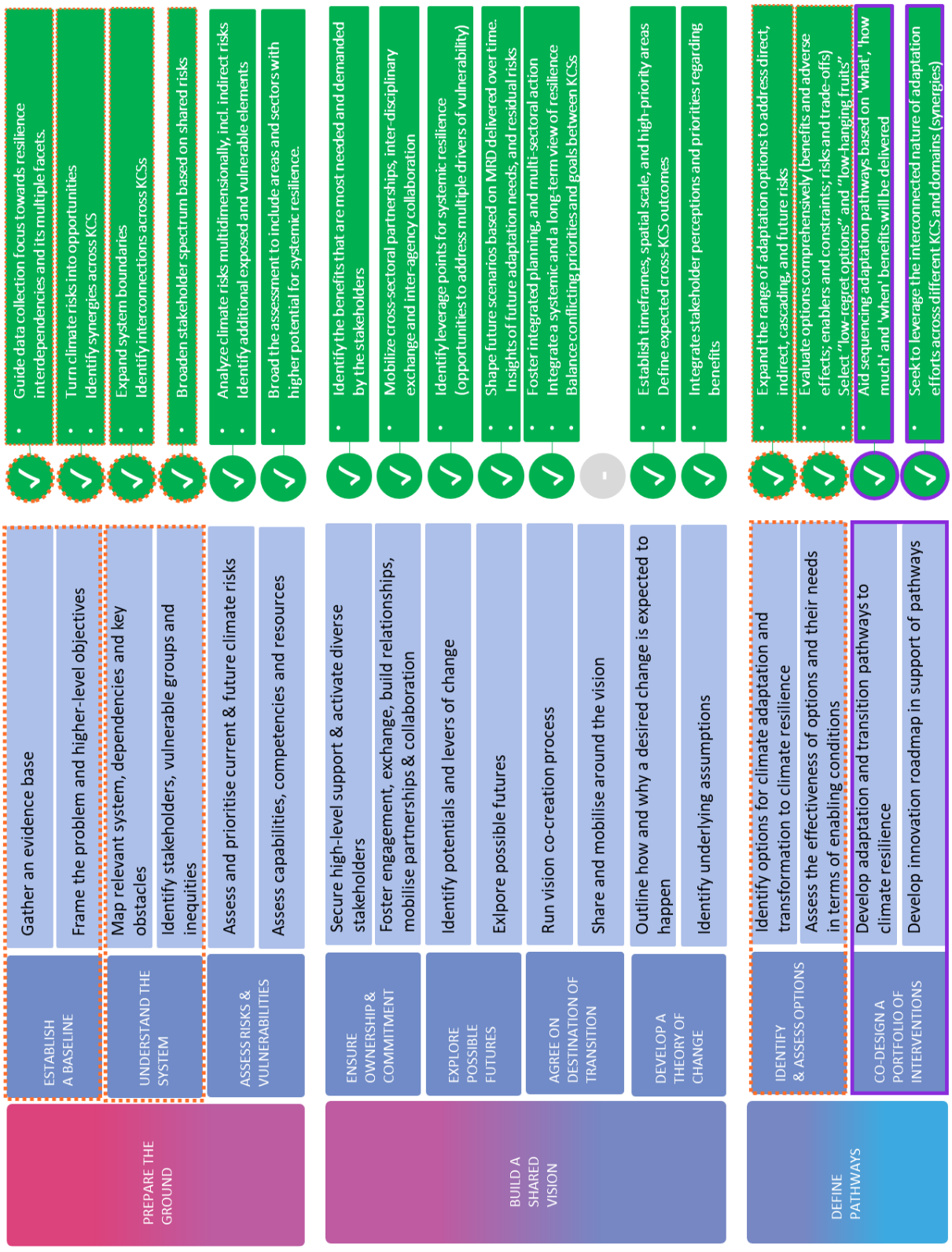

Figure 11. Interlinkages between the Regional Resilience Journey (RRJ) and the Multiple Resilience Dividends (MRD) Framework.

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5.2 Interlinkage with Other Deliverables

Since the MRD framework is integrated along the RRJ, it is interrelated with many other deliverables. Table 2 briefly describes the interrelation of the MRD framework with other deliverables within P2R, and the following two sub-sections explain in more detail the linkages with two closely related deliverables, namely D6.2 Methodologies for adaptation pathways formulation and D6.4 Methodologies for innovation agenda formulation.

Deliverable	Interrelation
D4.3 – Report on mapping and analysis of core enabling conditions	- The MRD framework can act as one of the enablers of transformational adaptation, and thus, of the RRJ. - The MRD framework recognises the influence of an enabling environment for selecting adaptation responses that can function effectively and sustainably over in the long run. - It analyses adaptation options either as enablers or constraints of the transformative regional adaptation vision.
D6.5 – Initial Catalogue of innovative transformative options, strategies and pathways	- Focus on systemic, synergistic, multi-functional options for climate adaptation. - Capacity to deliver multiple benefits as a criterion for selection ("*low-hanging fruits*"). - Prioritisation for those low-regret options by considering also adverse consequences and potential trade-offs.
D7.1 – Initial report on capacity building resources	- The MRD framework as innovative and transformative decision-making resource, part of P2R. - Overview of existing methods, tools and techniques for evaluating the adaptation options' capacity to deliver multiple dividends of resilience.
D7.4 – Adaptation pathways and innovation agendas produced with the supported regions	- Support on identification and appraisal of the adaptation options portfolio, as well as criteria for decision-making. - Aid in the identification, prioritisation, and sequencing of adaptation pathways. - Integrate stakeholder perceptions and priorities in the consideration of the appropriateness of adaptation options, relevant for innovation agendas.

Table 2. Interlinkages of the MRD Framework with other P2R deliverables.

5.2.1 The MRD framework and Formulation of Adaptation Pathways

The strongest connection of the MRD framework with the RRJ is in its third stage "Define Pathways". In light of that, this deliverable contributes to enhancing the Adaptation Pathways formulation, and thus the D6.2 concerning methodologies for developing adaptation pathways, in the following aspects:

- **Reframing the problem and objectives**: The MRD framework aims to turn climate risks into investment opportunities by harnessing overlapping priorities among multiple sectors. These overlaps between sectoral targets in the context of climate risk reduction and resilience building, namely synergies, are presented as opportunities for development (e.g., reducing background risk) achievable through integrated climate adaptation action. In consequence, it helps set more systemic goals and expected outcomes beyond the scope of DRR and CCA that align multi-sectoral actions and maximise regional adaptation resources and efforts.
- **Expand system boundaries:** By focusing on synergies, trade-offs, and interconnections between sectors, the MRD framework moves from a narrowed view of the problem to a more systemic perspective. Align with that, the range of stakeholders broadens,

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fostering a more diverse and multi-sectoral approach to planning Adaptation Pathways.

- **Comprehensive analysis of climate risks:** The MRD framework involves a multi-dimensional analysis of climate risks, with an understanding of how these risks propagate across the system and identifying additional elements that are exposed and vulnerable to hazards due to indirect and cascading effects. It also includes, when possible, examining the consequences of inaction, missed opportunities, and maladaptation, which can help shape the Adaptation Pathways.
- **Widen the range of adaptation options:** The MRD framework broadens the spectrum of adaptation strategies by leveraging synergies across KCS while taking climate risk reduction as a primary objective. This involves the identification of multi-functional responses as well as crafting packages of interconnected interventions that can address not only direct risks but also indirect, cascading, and future threats.
- **A thorough appraisal of options:** Each adaptation option is appraised in detail, evaluating both their benefits and adverse effects, focusing on potential trade-offs, conflicts, and risks of maladaptation brought by considering MRD thinking. This also includes the option's capacity to contribute to the regional adaptation vision.
- **Comparative analysis of options:** The MRD framework compares different adaptation options to determine their effectiveness. This includes assessing 'what' benefits they offer, 'how much' they deliver, and 'when' these benefits are realised, especially under varying climate scenarios. This provides valuable insights into future adaptation needs, the adaptation limits, and remaining risks based on the ability of adaptation strategies to yield multiple resilience dividends over different timeframes. The goal is to evaluate not only the performance in terms of risk reduction and adaptation, but also the resilience gains each option can offer to the overall system (co-benefits and synergies across KCS).
- **Integrating stakeholder perspectives:** Under the MRD framework, stakeholder perceptions and priorities regarding adaptation options and strategies are crucial. This involves assessing 'what' benefits and adverse effects are relevant and 'to what' degree based on stakeholder input and considering local conditions and dynamics.
- **Identifying the enabling environment for adaptation:** Part of the evaluation of options consists of recognising those factors that may enable or hinder the implementation of each adaptation option. This helps in choosing strategies that are not only effective but also sustainable in the long term.
- **Guiding decision points for Adaptation Pathways:** The MRD framework aids decision-makers by enhancing their understanding of adaptation choices and their various impacts on the established cross-KCS goals and expected outcomes. This includes a deeper comprehension of the interventions' performance beyond the traditional DRR and CCA perspectives, which helps establish key performance indicators and evaluation criteria in the Adaptation Pathways planning.

Each of these points contributes to a cohesive and well-rounded alignment between the MRD framework and the D6.2 "*Methodologies for adaptation pathways formulation*", ensuring consistency with the RRJ and future support to the regions.

5.2.2 The MRD framework and Formulation of Innovation Agendas

Since the MRD framework complements the D6.4 Formulation of Innovation Agendas, these two deliverables are closely interrelated in several key points of intersection as described below:

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- **Interconnectivity and synergies**: The MRD framework's approach to broadening system boundaries by emphasising interconnectivity – where intervention benefits cascade across sectors, scales, and space – resonates with the innovation agenda formulation's focus on identifying synergies between sectors, programmes and projects. Both approaches seek to understand and leverage the interconnected nature of climate adaptation efforts across different domains.
- **Strategic alignment**: The MRD framework contributes to formulating innovation agendas by recognising the multifaceted benefits of adaptation, which reinforces the importance of aligning innovative adaptation initiatives with broader systemic goals. It encourages a comprehensive view that integrates climate adaptation efforts into wider development objectives, ensuring that innovation roadmaps and portfolios are not just a collection of goals and projects, but a cohesive strategy aligned with long-term resilience and sustainability.
- **Multi-Dimensional Risk Analysis**: By providing a multi-dimensional analysis of climate risks, including indirect risks and the risks of inaction, the MRD framework enriches the formulation of innovation agendas. This deeper understanding of risks ensures that the agendas and associated investments are robust and equipped to handle the complexities of climate adaptation.
- **Broadening the scope of adaptation options**: The MRD framework aids innovation agendas by advocating for a wider range of interconnected, bundled, multifunctional adaptation responses. This approach ensures that portfolios are not limited to conventional solutions but include innovative, cross-sectoral adaptation initiatives that address multiple aspects of climate risks, as well as other societal goals, across KCS.
- **Promoting long-term perspective and sustainability**: The MRD framework's consideration of benefits unfolding over different periods guides innovation agenda formulation towards support solutions that are not only effective in the short term but also contribute to connecting multiple efforts with long-term goals, such as building systemic resilience. This long-term perspective is important for ensuring the sustainability of both adaptation efforts and innovation processes, recognising that the outcomes and benefits materialise over extended periods.
- **Cross-sectoral collaboration and stakeholder engagement**: The MRD framework aligns with the collaborative aspect of innovation agendas by emphasising cross-sectoral action shared across multiple stakeholders. It underscores the importance of involving a diverse range of stakeholders and sectors, fostering a more inclusive and comprehensive approach to transformational adaptation.
- **Promoting experimental learning**: The MRD framework underscores the importance of monitoring and evaluation systems, measuring the success of interventions beyond immediate and conventional DRR/CCA outcomes and allowing for learning from diverse adaptation efforts as they are implemented. This is intertwined with the idea of innovation agendas of dynamic experimentation, continuous learning, and responsiveness to changing conditions and new insights.

Overall, the MRD framework and the formulation of innovation agendas focus on serving multiple public values and co-creating long-lasting, positive, systemic impacts with stakeholders. The interlinkage between these two deliverables can lead to more sustainable, cohesive, well-geared journeys towards climate resilience and system transformation.

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5.3 Paving the Way to Transformational Adaptation

The MRD framework represents a significant shift in decision-making processes for climate adaptation. It recognises inefficiencies in decision-making processes that are no longer sufficient and responsive to the challenges posed by a rapidly evolving climate. Thus, the framework encourages decision-makers to go beyond incremental adaptation and re-evaluate the full potential of resilience-building to impact the KCS of a regional or urban system. By focusing on patterns, trends, and underlying structures rather than events and visible impacts, the framework aims to address risk drivers fundamentally.

The MRD framework supports transformative thinking by redefining decision-making values and leveraging updated and multi-disciplinary knowledge to build the case for systemic resilience in the climate adaptation field. In a flexible and adaptable fashion, the framework offers an innovative way to evaluate options for building climate resilience efficiently and effectively, regardless of the regional contexts and the system dynamics and complexities.

The MRD framework can be considered as a lever of the system's transformation (Figure 12) because:

- It aligns with the region's long-term vision to foster a sustained and durable adaptation process.
- It harnesses and creates synergies between climate adaptation and other development goals, amplifying the impact of adaptation responses.
- It aims to have a broad and profound impact on the system's resilience, addressing underlying drivers of risks.
- It recognises the multi-faceted nature of building climate resilience by considering its implications across the different components or developmental aspects of the system, beyond the risk reduction or adaptation outcomes.
- It looks after a widespread acceptance and ownership of the adaptation process through a hybrid approach in which decision-makers and multi-sectoral stakeholders exchange information constantly and iteratively.
- It stimulates innovation regarding adaptation options by focusing on systemic, interconnected, combined, and multifunctional ways to build climate resilience.

At its core, the MRD framework contributes to the system's transformation by encouraging systemic adaptation and resilience. Through a multi-targeted approach that exploits the hidden benefits of building climate resilience, the MRD framework can prompt sustainable, effective, and transformational decisions able to address underlying vulnerabilities and multiple risks in an integrated manner.

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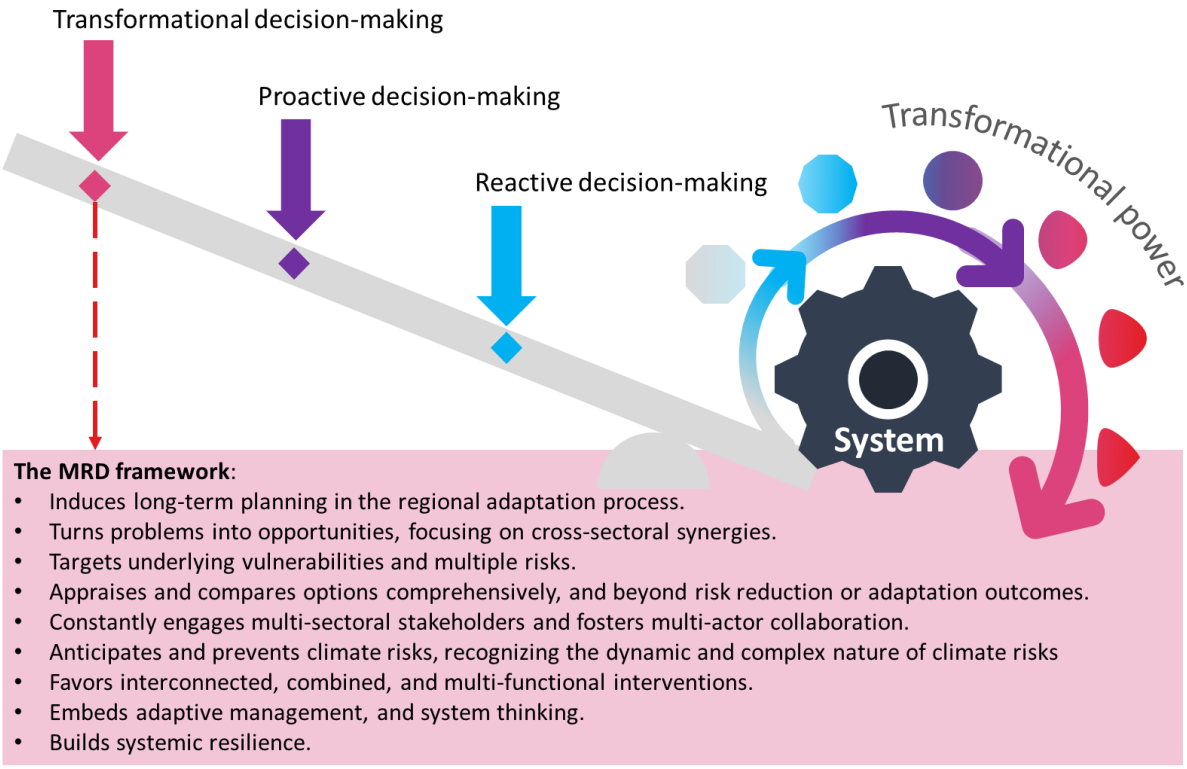

Figure 12. The MRD Framework as a decision-making approach for transformational adaptation.

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Conclusion

For European regions, the MRD framework can be a powerful tool that can help guide climate adaptation decisions towards a more sustainable and resilient future. By facilitating the selection of robust, low-regret, synergistic, multifunctional, and cost-effective adaptation responses, the MRD framework lays a solid foundation for strategic investments in climate resilience.

The MRD framework offers comprehensive guidance to unveil the multiple benefits of adaptation responses across various sectors (i.e., KCS). This systemic approach, captured in the framework, goes beyond the traditional DRR and CCA focus, bringing a fresh perspective for adaptation planning that extends to diverse areas and domains within a system. With a variety of existing methods and techniques, ranging from cost-benefit analysis and narrative-based approaches to robust decision-making, the MRD framework can be operationalised and adapted to the diverse resilience maturity levels of European regions. Whether applied in concrete urban environments or broader administrative levels, the MRD framework adjusts seamlessly, ensuring a tailored approach that addresses the specific needs, challenges and opportunities unique to each region.

The MRD framework is an integral part of the RRJ, which significantly enhances the possibilities to produce successful regional adaptation strategies and, ultimately, build systemic resilience more effectively. By emphasising the importance of considering economic, social, and environmental outcomes when making decisions, the MRD framework induces a systemic, multi-sectoral approach to building climate resilience. Therefore, it provides an alternative approach to framing, identifying, appraising, choosing, implementing, and evaluating adaptation responses that can broaden and strengthen the value proposition for regions to invest in climate adaptation. Most importantly, the MRD framework helps create an environment that enables climate adaptation, guiding regions to effectively address the complexities and scale of climate challenges.

The MRD framework's alignment with other key deliverables, such as methodologies for adaptation pathways and innovation agenda formulation, further strengthens its role within the RRJ logic. On the one hand, it enhances the Adaptation Pathways formulation by broadening the spectrum of adaptation options, comprehensively assessing them, and focusing on the realisation time required to deliver multiple benefits. This can provide valuable insights into the sequencing of actions and potential future adaptation needs. On the other hand, it supports the Innovation Agenda formulation by fostering interconnected, bundled and multifunctional adaptation responses, encouraging cross-sectoral adaptation action, and focusing on synergies between adaptation and wider development objectives. The alignment between the MRD framework and these two other deliverables increases the likelihood of creating a more meaningful, comprehensive, sustainable, and transformative resilience journey for the regions.

Thus, the MRD framework represents a fundamental shift in the prevailing decision-making paradigm in the adaptation context. It introduces a transformational approach that prompts decision-makers to embrace a more comprehensive, forward-thinking strategy. By doing so, the MRD framework not only addresses the challenges posed by climate change but also seizes the opportunity to leverage systemic resilience as a proactive and multifaceted solution for climate-resilient development.

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Annex 1- Gaps

Table 3 summarises some of the most critical gaps in the operationalisation of the resilience dividend concept. Addressing these gaps can enhance the applicability of the MRD framework and help decision-makers allocate adaptation-related resources more effectively, with the aim of achieving equitable outcomes and improving the implementation of future building-resilience actions.

GAP	DESCRIPTION	SOURCE
Low measurability	Many varied benefits—some are not easily measurable (e.g., increase of social cohesion, biodiversity)	(Heubaum et al., 2022)
Limited data	There is not enough data for some benefits (e.g., innovation rate, competitiveness)	(Mechler and Hochrainer-Stigler, 2019; Heubaum et al., 2022; Rözer et al., 2023)
Fragmented analysis	Negative externalities, trade-offs and indirect side-effects (i.e., adverse effects) must also be factored into the analysis.	(Mechler and Hochrainer-Stigler, 2019)
Unclear attribution to the intervention	Lack of objective guidelines on what counts as an additional benefit (e.g., improved water security, reduced outmigration) that assures that the additional benefits are due to resilience intervention and not from other actions (e.g., development projects, conservation efforts).	(Fung and Helgeson, 2017; Heubaum et al., 2022; Rözer et al., 2023)
Lack of an equity perspective	The distributional aspects (i.e., spatial, social and temporal distribution of benefits, burdens, and adverse effects) are still missing in the analysis and quantification.	(Rose, 2016; Mechler and Hochrainer-Stigler, 2019; Helgeson and O'Fallon, 2021; Heubaum et al., 2022)
Low comparability	No agreement on what indicators should be considered for analysing the multiple benefits.	(Heubaum et al., 2022; Rözer et al., 2023)
Not people-centered	Identification of benefits most needed and demanded by the community is often missing.	(Rözer et al., 2023)
Difficult framing	Difficulty in defining the scope and different time frames of each benefit (when and how it will be delivered), as well as the required parameters to measure impacts on both "with" and "without" disaster scenarios (e.g., affected people and property damages can only be valued if a disaster strikes).	(Heubaum et al., 2022; Rözer et al., 2023)
Non-quantifying benefits	Literature mainly focused on identifying benefits but not on quantifying them.	(Fung et al., 2021)

Table 3. Existing gaps in the applicability of the MRD approach.

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Annex 2- Data collection and analysis

A. Search strategy to identify additional literature.

To source and select the additional literature from the Scopus database, the inclusion criteria were as follows:

- Search within: Title, Abstract, Keywords
- Search string: ("co-benefits" OR "benefits") AND (“social” OR “environmental” OR “economic” OR “institutional” OR “well-being”) AND ("resilience" OR "adaptation" OR "mitigation" OR "disaster risk reduction" OR “conservation” OR “sustainab*” OR “environmental AND management”) AND (“assess*” OR “approach” OR “framework” OR “method*” OR “tool”)
- Date: 2016-2023.
- Language: English, Spanish
- Subject areas: business and management; decision sciences; social sciences; multidisciplinary; energy; engineering; earth and planetary sciences; agricultural and biological sciences; economics, econometrics and finance.

B. Coding Structure used for Content Analysis

Each of the articles underwent content analysis, classifying the information into the following coding structure :

- Benefits: Categorisation or mention of dividends, meaning associated benefits and co-benefits.
- Costs: Categorisation or mention of adverse effects and impacts.
- Indicator: Parameters, criteria, and indicators used to measure dividends, co-benefits, or even co-costs (includes proxies too).
- KCS: Key elements and specificities of the KCS that must be considered, e.g., contextual factors and conditions of a KCS.
    - NBS: Ecosystems and Nature-based Solutions
    - LUFS: Land Use and Food Systems
    - HW: Health and wellbeing
    - WM: water management
    - CI: critical infrastructure
    - LES: local economic systems
- Addon: Aspects from other decision support tools that can enhance the Framework (e.g., steps, approach, framing, visualization).
- Framework: a framework that was introduced, including figures and an explanation.
- Tool: Mention of a specific tool, technique, or method for recognising/analysing/valuating resilience dividends, benefits, or co-benefits.
- Challenge: Difficulties related to method application, decision-making, or adoption.
- Concept: Definition of relevant concepts or terms.
- Key: relevant findings related to resilience dividends to be considered.
- Stakeholder: Ways to engage stakeholders, integrate their perspectives, interests, and needs, or points about requirements and capacities related to applying the resilience dividends concept.
- Example: Case studies or theoretical exemplars that can be helpful.
- Decision: Factors and considerations relevant to the decision-making process.

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Annex 3- Other methods and techniques to characterise resilience dividends.

- Participatory Assessments (e.g., Delphi method, Focus Group Discussions, Local Forums, Face-to-face interview)

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Qualitative	- Help identify the local values attached to benefits and the wide range of benefits and potential hidden impacts. - Integrate historical perspective of risks, shocks and stresses. - Links community perceptions and local knowledge with science.	- Primary data from local stakeholders. - Secondary data to provide a baseline.	Low	- Difficult to replicate and validate the data. - It can be time-consuming and resource intensive. - Prone to subjectivity and other biases.
Source: Mechler and Hochrainer-Stigler, 2019				

- Portfolio Analysis

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Quantitative	- Analyses the joint action of various measures. - Focuses on maximising expected return rates and minimising portfolio variance. - Highlights the trade-offs between investment returns and riskiness. - Account for uncertainty.	- The average effectiveness (or expected return) of each investment. - The variance, and the co-variance of return for each option over the range of climate scenarios. - A minimum level of effectiveness. - Probabilistic climate information.	High	- Data and resource intensive - Highly dependent on quantitative data and expertise. - It static, responding to current uncertainties.
Source: Watkiss et al., 2015				

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- Real Option Analysis

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Quantitative	- Quantifies the investment risk with uncertain future outcomes. - Accounts for the value of flexibility: alter the timing of investment, or to change plans (continue, stop, expand, contract) at some points in response to unforeseen conditions. - Considers how decisions made in later stages affect earlier ones.	- Probabilistic climate information - Quantitative impact data	High	- Data intensive - Incorporation. of risk preferences remains limited. - Needs to identify decision points in complex evolving climate pathways.
Source: Watkiss et al., 2015				

- Computable General Equilibrium

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Quantitative	- Simulate how an economy responds to changes in policy or technology. - Quantify the impacts and benefits of resilience interventions. - Compares economic outcomes of resilience investments versus those without such investments.	- Actual economic data (data on key supply and demand parameters).	High	- Heavy reliance on assumptions about optimising behaviour, competitive markets, and flexible relative prices. - Data-intensive. - Potential problems due to the lack of consistency between changing variables during the transitions from one

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				equilibrium to another.
Source: Fung et al., 2021				

- Analytical Economic Modelling (e.g., agent-based, environmental, game theory, micro- and macroeconomic models).

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Quantitative	- Works in the absence of data and without mired in detail (high abstraction level). - Results are often precise with general statements about what can or cannot happen under certain conditions and may illustrate gaps. - Models the best set of interventions with respect to multiple objectives for maximising social welfare. - Simulates the effects of various adaptation options, considering changes in climate, markets, and adaptive processes of different community groups.	- Historical, cross-sectional, and time-series data related to benefits. - Data on market, economic agents, policy, behavioural, social, environmental, including external shocks.	High	- Relies heavily on assumptions that may not always accurately reflect real-world conditions (over-simplification) - Limited in analysing ripple and cascading effects of changes in variables. - Often faces data limitations (e.g., outdated, incomplete, or subject to measurement errors). - Add uncertainty (due to the model).
Source: Wu et al., 2018; Fung et al., 2021; Jia, Chen and Du, 2021				

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- Econometrics and Statistical analyses

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Quantitative	- Evaluate correlations of direct and indirect impacts of resilience interventions. - Estimate economic outcomes relative to the counterfactual without resilience investments. - Infer patterns from data. - Quantifies uncertainty in terms of standard errors or confidence intervals.	- Real-world data (observations and predictors)	High	- Little empirical work on quantifying co-benefits. - Requires data a finer scale and/or large number of observations and predictors.
Source: Fung et al., 2021				

- Simulation models

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Quantitative	- Applicable for different climatic conditions. - Considers uncertainty. - Highly flexible and adaptable for testing and experimentation. - Effective for analysing complex and dynamic systems. - It can provide a visual, realistic	- Initial conditions, parameters, constrains, and external factors.	High	- Data and computing intensive. - Assumptions can introduce bias and affect the results' validity. - Causes-outcomes relationships can be untraceable (black box effect).

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	representation useful for communication purposes.			- Overfitting (poor performance with new data)
Source: Jia, Chen and Du, 2021				

- Geospatial Analyses

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Qualitative, quantitative, or mixed	- Allows to understand the effects before and after the resilience intervention, including the shocks-related ones (e.g., flooding) at different spatial scales. - Can be couple with other methods (e.g., MCA) and models (e.g., economic).	- Geospatial data (raster, vector, satellite and aerial imagery) - Geo-statistics - Meta-data	Medium	- Relevant aspects such as, justice, equity, stakeholder perceptions are hard to integrate. - Often faces data issues related to quality, integration, accuracy, consistency, and affordability. - Computation intensive.
Source: Grafakos, Gianoli and Tsatsou, 2016; Doeffinger and Rubinyi, 2023; Higuera Roa et al., 2023				

- Grey theory for decision-making

Type of Analysis	Strengths	Input	Expertise	Weaknesses
Mixed	- Well-suited for situations where data is incomplete or uncertain. - It can accommodate imprecise information and provide useful insights. - Allows to consider multiple criteria and factors at once.	- Historical data of disruptions, damages, or recovery times. - Risk data - Performance metrics. - Expert opinions. - Stakeholder preferences. - Grey data (lower and upper bounds along with central values to represent uncertainty).	High	- Sensible to the quality and quantity of data. - Model-dependant. - Not very intuitive carrying potential transparency issues.
Source: Wu et al., 2018				

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