Opportunities to integrate climate change adaptation and mitigation across strategic, adaptive and transformative pathways

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Abstract: Calls to integrate adaptation and mitigation promote synergistic climate action. However, narrow, intervention- or sector-specific perspectives obscure complexities shaping how these agendas are operationalised in practice. This paper explores opportunities for integration from a systemic perspective, viewing climate resilient futures as emerging from diverse changes across sectors, scales, societal domains and logics of change. We co-created strategic, adaptive and transformative climate resilient pathways combining options across sectors and societal domains in five European case studies. Our mixed methods approach evaluated these pathways to identify integration opportunities. We show that the greatest opportunities lie in cross-sectoral actions and transformative logics, addressing systemic change in institutional, economic and cultural paradigms. Nature-based solutions enhance climate resilience while sequestering carbon. Additionally, mitigation measures improving community infrastructure and democratising energy systems generate adaptation co-benefits by strengthening social and human capital. These findings underscore the value of systemic approaches to advance integrated and ambitious climate action.

Keywords: pathways, climate resilience**,** nexus, IPCC, social-ecological systems

1. Introduction

The impacts of climate change are already felt and worsening [1]. These impacts manifest as the increasing severity and unpredictability of extreme weather events, sea level rise and shifting climate regimes, affecting people and nature around the world. In response, scientists and governments worldwide are calling for urgent transformative change [1–3]. These changes involve pursuing adaptation at scale across multiple sectors to build resilience to the already-felt and projected future impacts of climate change [4], while also rapidly dismantling the current fossil-fuel driven economy to reduce greenhouse gas emissions [5,6]. Despite decades of global commitments and local action, the speed and scale of implementation of both the climate change adaptation and mitigation agendas has been insufficient. Transformational adaptation will be required under severe global warming scenarios, but the majority of existing or planned climate risk management (i.e., adaptation) is incremental [7,8]. Moreover, climate change mitigation efforts have so far failed to bend the emissions curve [6], requiring a shift from incremental to transformative action for reduction of emissions [9,10].

Humanity is now faced with the challenge of simultaneously stewarding a rapid and sustainable transition to net zero greenhouse-gas emissions while coping with the impacts of a changing climate. Yet, actions to address the adaptation and mitigation agendas have so far remained largely separate due to differences in the scale and sector of implementation, divides between research communities, persistent knowledge gaps and barriers in finance and governance [11–13]. Recently, the Intergovernmental Panel on Climate Change (IPCC) and the wider climate research community have called for efforts to better integrate climate change adaptation and mitigation [14], as there are numerous trade-offs and synergies between solutions [11,15,16]. For example, some mitigation solutions can have detrimental effects on livelihood options or local ecosystems, reducing the capacity to adapt to climate change [12,17], and nature-based solutions for adaptation contribute to mitigation through sequestering carbon [18].

Identifying opportunities for integration across these dual agendas is required to translate this global dialogue to implementation at local, regional and national scales. Such efforts demand new analyses that identify synergies and minimise trade-offs between interventions [12], yet there are significant knowledge gaps about opportunities for more coordinated, synergistic action at the scale of decision making [13]. Additionally, existing studies mapping synergies and trade-offs adopt a narrow view of integration as intervention-specific. These studies analyse high-level, qualitative actions too generic for on-the ground decisions, sector-specific opportunities, or levels of integration within existing plans [19–22]. While targeted assessments can be informative, they lack more expansive inquiry into more complex factors influencing the nature of and motivation for adaptation and mitigation. Concretely, adaptation involves localised solutions motivated by downscaled present and future climate impacts, so both solutions and their benefits are targeted to the place and sector of implementation [23,24]. In contrast, mitigation is motivated by international commitments for the future benefit of all, connecting local sustainability transitions to systems and priorities at higher scales.

There is a crucial need for research that adopts a more systemic view, exploring opportunities for integration across multiple dimensions of climate action to inform decision making and future research. Doing so can yield previously unknown opportunities for integration while surfacing essential changes in underlying views, structures and practices required to shift from incremental to transformative change [25]. To leverage this opportunity, novel approaches are required to elicit broad patterns and examples across sectors, including cross-sectoral interactions [26] and across scales [27] and

to explore more fundamental differences between the adaptation and mitigation agendas. This deeper inquiry can be addressed by identifying opportunities for integration across societal domains and logics of change. Societal domains are functional contexts where action can take place, such as in governance, politics, the economy, technology, lifestyles and culture [28]. Logics of change are underlying assumptions regarding how and why change occurs within systems [29]. For example, adaptive logics start from the present, adjusting existing systems to forecasted impacts, while transformative logics start from a desirable future and propose ambitious actions to achieve it.

Co-creative, transdisciplinary research approaches are increasingly used to explore pathways to achieve sustainable futures [29–31], offering a means to identify opportunities for integration across these multiple dimensions. The objectives were to 1) co-create climate resilient pathways that include adaptation and mitigation options (i.e., measures) across logics of change, sectors and societal domains in five case studies in Europe at diverse scales and 2) analyse and evaluate the pathways to identify broad patterns and examples regarding opportunities for integration that can inform more synergistic climate research and action.

2. Methods

A transdisciplinary methodology was used to identify opportunities to integrate the climate adaptation and mitigation agendas. The research was conducted as part of the DevelopIng STratEgies by integrating mitigatioN, aDaptation and participation to climate changE Risks (DISTENDER) Horizon Europe project (www.distender.eu), involving 31 partner organisations to explore robust options for integrating adaptation and mitigation in Europe. The overall methodology is visualised in

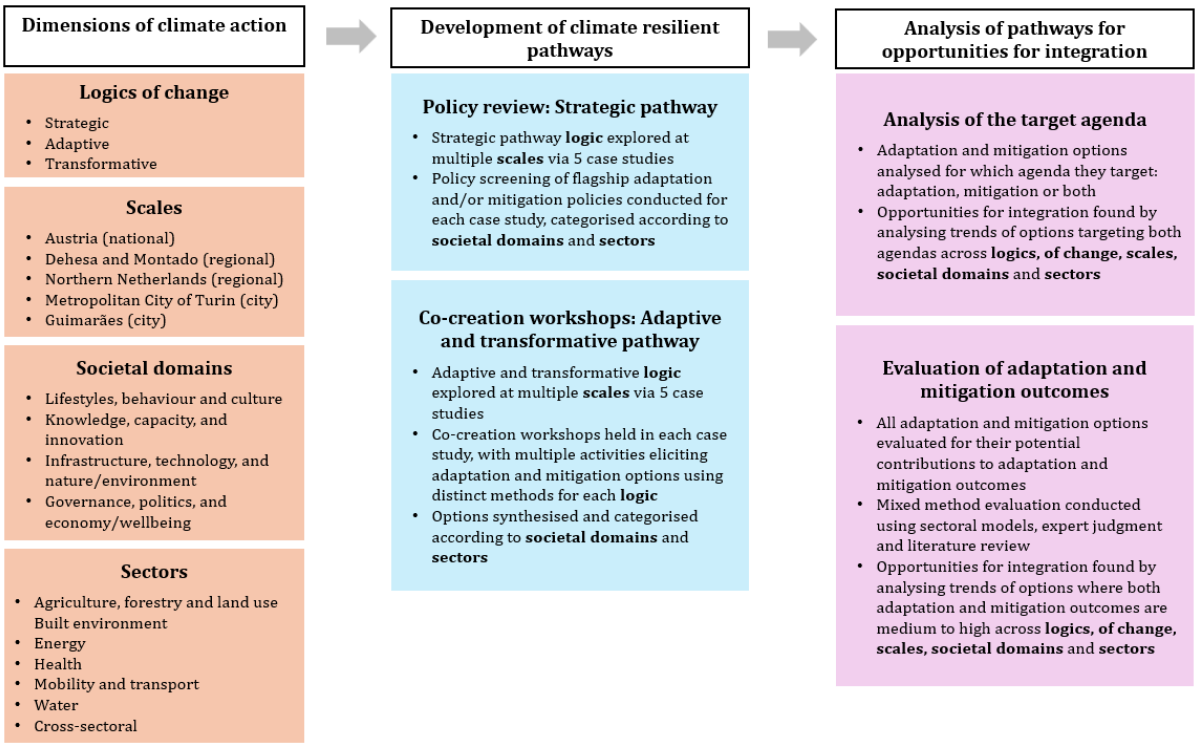


Figure 1 and detailed in subsequent sections.

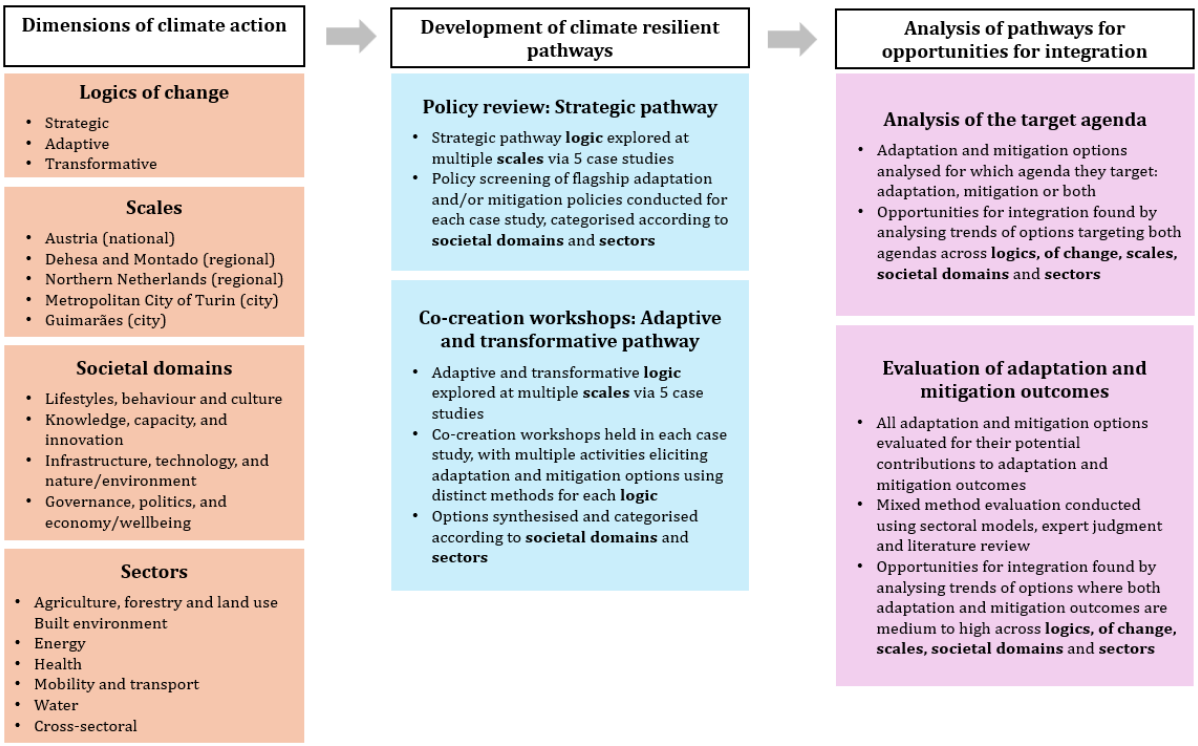


Figure 1: Summary of methodology to identify opportunities for integration of climate change adaptation and mitigation across logics of change, scales, societal domains and sectors.

2.1 Conceptual framework: dimensions of climate action

This section presents the conceptual framework that defines the dimensions of a systemic view of climate action that were explored in this study. Each of these dimensions were explored for opportunities for integration.

Logics of change

Adaptation and mitigation options were explored across logics of change, which are the underlying assumptions regarding how change occurs within systems that vary in their goal, scope and methods. The logics of change considered were guided by an adapted version of the Sustainable Future Scenarios (SFS) framework (Iwaniec et al. 2020), which describes alternative future pathways according to contrasting underlying logics of change (Figure 1). *Strategic* pathways consider the outcomes of existing and planned options, *adaptive* pathways build on existing and planned options by adapting them to forecasted change, and *transformative* pathways include more ambitious actions to achieve a vision of a climate resilient future. These different logics reflect variations in perceived plausibility, i.e., likely to happen, with the strategic pathway as most plausible and the transformative as least. The logics also vary in perceived desirability, with the transformative pathway as generating the most desirable options and strategic as least. These contrasting logics were used to generate three distinct pathways in each case (see section 2.2).

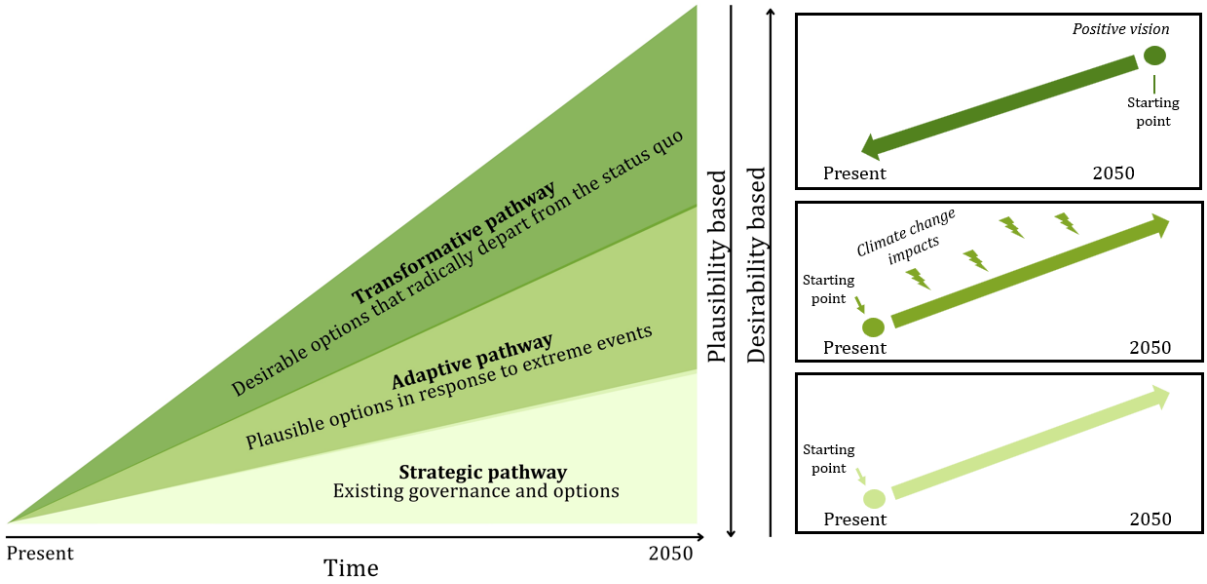


Figure 1: Strategic, adaptive, and transformative logics of change underpinning the pathways. Adapted from Iwaniec et al. (2020).

Scales

Adaptation and mitigation options were explored across scales by implementing a common approach in five European case studies representing different scales in contexts with unique challenges, as summarised in Table 1: the country of Austria (national), the Northern Netherlands (regional), the Dehesa and Montado region, Spain and Portugal (regional), Guimarães, Portugal (city), and the Metropolitan City of Turin, Italy (city).

Table 1: Key characteristics of five case study regions across scales

Case study	Scale	Area	Population	Partner
Austria	National	83,858 km^2	9.2 million (2025)	Austrian Ministry of Innovation, Mobility and Infrastructure (formerly Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology)
Dehesa and Montado (Spain and Portugal)	Regional	74,361 km^2 including Extremadura Region and Tagus basin	1 million (2021) in Extremadura	European Agroforestry Federation
Northern Netherlands	Regional	11,200 km^2 including Provinces of Groningen, Friesland and Drenthe	1.7 million (2022)	Hanze University of Applied Sciences, Water Authority Noorderzijlvest
Metropolitan City of Turin (Italy)	City	6,827 km^2 including metropolitan area	2 million	Metropolitan City of Turin

City of Guimarães (Portugal)	City	241 km^2	157,000	City of Guimarães

Austria

Austria is a land-locked country with nine federal provinces. Responsibility for climate adaptation and mitigation lies at the national, provincial and municipal levels. The country includes part of the eastern Alps, the Danube region, and areas of high forest cover. Austria's economy is dominated by the service sector, including tourism, and the industrial sector, notably manufacturing, also plays a key role. Austria's main sources of greenhouse gas (GHG) emissions are the industry, transportation, and building sectors. Key climate challenges include rising temperatures, with heatwaves becoming more frequent, changing precipitation patterns, and an increased risk of natural hazards, such as floods, droughts, and landslides.

Dehesa & Montado, Spain and Portugal

Dehesa and Montado are agrosilvopastoral systems found in the southwestern region of the Iberian Peninsula in Spain (Dehesa) and Portugal (Montado). Dehesa and Montado is comprised of wood pastures at different tree cover densities used by a mix of livestock including ruminants and Iberian pigs and tree species. Climate adaptation and mitigation is directed by landowners, farm managers, and workers, regional government officials, and policy makers at different levels. Agroforestry is a key sector, necessitating options that strengthen farming practices while reducing their vulnerability. Key climate risks include increased drought frequency, more extreme precipitation events, and rising temperatures with prolonged summer periods, which exacerbate pests and diseases, accelerating tree mortality and dieback.

Northern Netherlands

The Northern Netherlands is a region consisting of three provinces: Groningen, Drenthe, and Friesland. Climate mitigation is primarily governed by these three provinces while adaptation is primarily governed by municipalities and regional water authorities. The region is characterized by expansive rural areas and flat, low-lying landscapes, with some urban centres scattered throughout the provinces. It borders the North Sea along the coasts of Groningen and Friesland, and has various rivers, lakes, and wetlands. The region is dominated by agricultural activities and plays an important role in energy production, both key sectors contributing to GHG emissions in the Netherlands. Key climate challenges include rising sea levels, increased flooding and drought risk, and high temperatures.

Metropolitan City of Turin, Italy

The Metropolitan City of Turin (CMTo) is an Italian administrative body composed of 312 municipalities. Climate adaptation and mitigation is implemented by municipalities, guided by the metropolitan and regional levels. CMTo covers a heterogenous territory, including dense urban in the plain central area and rural territories in the mountain Alps and valley. It includes many rivers and Natura2000 areas. The dominant economic sector is shifting from manufacturing in the automotive industry to the service sector. Main climate change mitigation priorities include improving land use practices and improving energy efficiency. Key climate change impacts in CMTo include droughts, flooding, and extreme temperatures, posing risks to infrastructure, water supply, air quality and public health.

Guimarães, Portugal

Guimarães is a city in northern Portugal. At the municipal level, the Office of Energy Efficiency and the Department of Territory Development are responsible for climate mitigation and adaptation. Guimarães has a mix or urban areas, agriculture, and forest, and the territory is cut by three rivers. Its main economic sector is industry, including textiles, footwear, and metal mechanics. The city is known for its cultural heritage, with its historic town centre a UNESCO World Heritage Site and tourist attraction. Main sources of GHG emissions include the energy and transportation sectors. Key climate challenges include forest fires, flooding, and droughts, posing a risk to sectors such as public health, forestry, and cultural heritage.

Societal domains

Adaptation and mitigation options were developed across societal domains, which are functional contexts within a society where action can take place including and beyond the economy. The typology was developed by combining and adapting typologies used in prior studies [28] in consultation with researchers and case study partners.

- Lifestyles, behaviour and culture (LBC): options that shape people's daily lives, their everyday behaviours and how they interact in the public sphere;
- Governance, politics, and economy/wellbeing*;* (GPE): options that influence policy/governance instruments, changes to institutional structures and processes, and/or economic incentives;
- Infrastructure, technology, and nature/environment (ITE): options that leverage the creation/use/management of hard/green infrastructure, technology, and other aspects of nature/environment;
- Knowledge, capacity, and innovation (KCI): options targeting the generation of knowledge, data, capacity, or innovative solution.

Sectors

Adaptation and mitigation options were explored across sectors, which are functional areas of the economy. A standardised list of sectors was used across all case studies, which was selected in consultation with researchers and case study partners and combined and slightly adapted in each case study based on the unique context and priorities:

- Agriculture, forestry and land use (AFOLU)
- Built environment
- Energy
- Health
- Mobility and transport
- Water
- Cross-sectoral

2.2 Development of climate resilient pathways

Three climate resilient pathways were developed across the scales represented in each of the five case studies according to the three logics of change – strategic, adaptive and transformative. Within each pathway, adaptation and mitigation options were developed across sectors and societal domains.

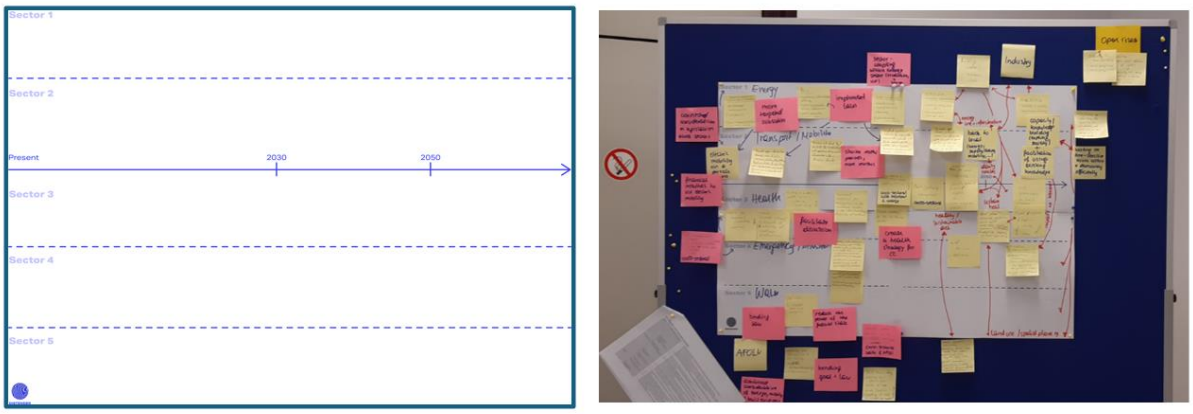
Policy review: development of the strategic pathway

The strategic pathway was developed through a policy screening and synthesis of adaptation and mitigation options from existing governance and climate policy. Relevant policy documents were identified from flagship adaptation and/or mitigation policies at the scale of the case, supplemented with national adaptation strategies, national long-term strategies and the national energy and climate plans required by the European Union. The cut-off date for inclusion was December 2023, although not all adaptation and mitigation options had been implemented at the time of the screening. Information about individual adaptation and mitigation options were extracted from each of these documents including a description, whether it is targeting adaptation or mitigation, and its corresponding sector [32].

Co-creation workshops: development of the adaptive and transformative pathways

The adaptive and transformative pathways were developed through co-creation workshops in each of the five case studies in March and April of 2024. All workshops were one full-day, in-person workshops except for Dehesa and Montado, which took place online over two consecutive half-days. For accessibility, workshops were facilitated in native languages by a local facilitation team that was trained by researchers, except for English language facilitation in Austria due to partner preference. Workshop participants were selected based on the Prospex-CQI method [33] ensuring a diversity of perspectives and expertise related to climate change adaptation and mitigation (Table S1). All data during the workshop was captured by dedicated notetakers for each breakout group and data captured on sticky notes and posters.

The adaptive pathway explored how options existing in the present (i.e., from the strategic pathway) may need to be adapted or enriched to respond to future climate change impacts. Workshop participants were split into four breakout groups to ensure diversity of professional background and institutional affiliation. The groups chose the most important options from the strategic pathway to achieve between now and 2030 for their sector and added them to a timeline (Figure 2). Participants were then shown simplified summaries of the downscaled climate change and sectoral impact modelling conducted for their case study by the DISTENDER project [34]. Using this new information, participants were asked to generate adaptive options to the year 2050 that respond to new challenges and/or increased level of ambition required to respond to projected climate impacts (e.g., maintaining or improving effectiveness or feasibility).



(a) (b)

Figure 2: Example workshop materials for the adaptive pathway. (a) Poster used to guide adaptive pathway generation and (b) example of a completed poster for the governance, politics and economy group from the Austria case.

The transformative pathway was developed by envisioning a desirable climate resilient future in 2050 and developing transformative options to achieve it. Visions in sectoral breakout groups guided by the phases of Theory U [35] to facilitate the creation of imaginative visions of a climate resilient future in the case studies (Figure 3). The steps of the process included *observe* by viewing and discussing inspirational photos and textual statements collected from participants via a survey prior to the workshop, *reflect* through a guided visualisation and free writing and drawing exercise to imagine a climate resilient future for the case and sector in 2050 and *act* to crystallize their reflections and collectively map their ideas for visions of a climate resilient future. In the Austrian and Northern Netherlands cases, an additional process was added to enable engagement with 'silent' voices to bring in notions of intergenerational and interspecies justice [36,37], such as visioning from the perspective of a wild be (Figure 3a).

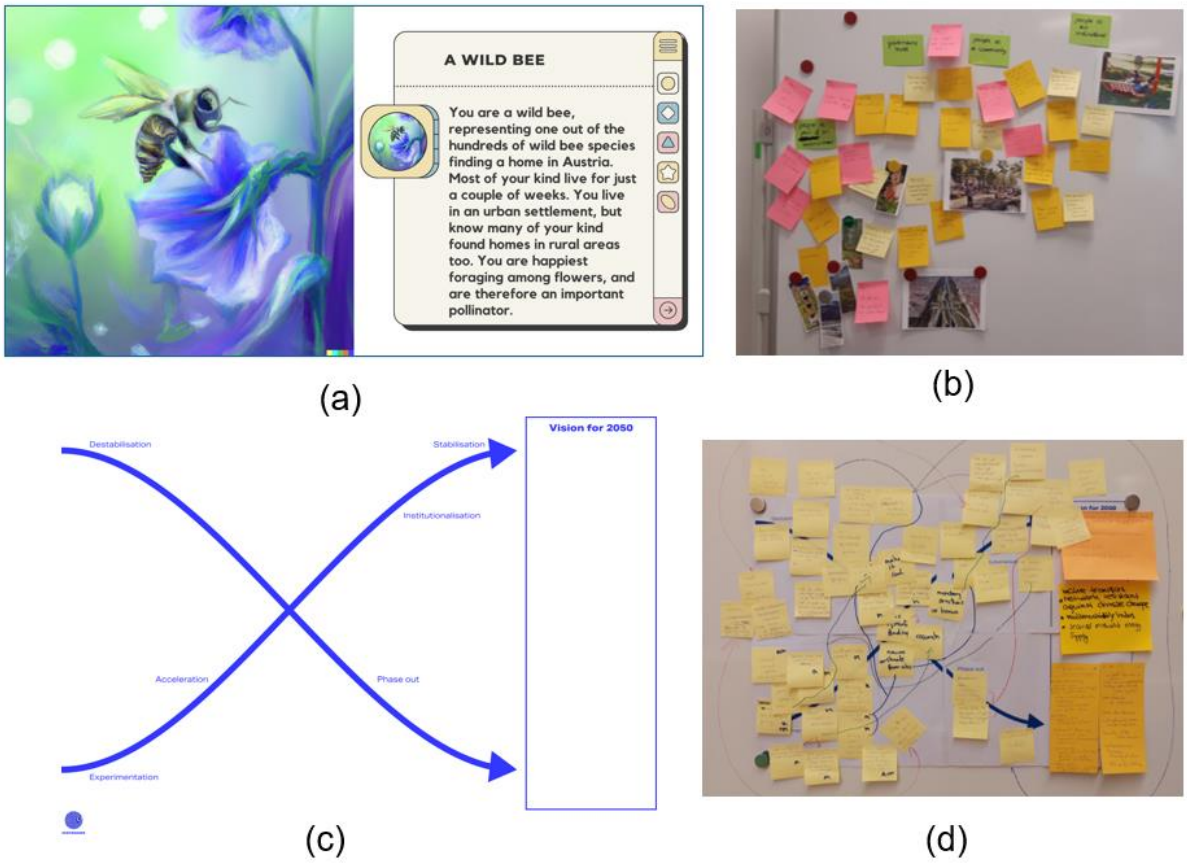


Figure 3: Example workshop materials for the transformative pathway. (a) Example of 'character card' used for additional reflection phase in workshop 2, (b) an example of a visioning board from the Austria case study, (c) poster used to guide transformative pathway generation and (d) example of a completed poster for the infrastructure, technology and nature/environment from the Austria case.

In a subsequent session, participants from each sectoral visioning group brought their relevant vision elements back to the societal domain groups used to generate the adaptive pathway. After sharing the elements of their vision, they co-created adaptation and mitigation options to achieve the vision, guided by the X-curve framework (Figure 3), which provides a structured approach to create action-

oriented knowledge about societal change [38]. Participants first discussed options in their domain that would facilitate build-up of the desirable aspects of the system (i.e., experimentation and acceleration) and breakdown of the undesirable aspects (i.e., destabilisation) in the near-term to achieve the vision. They then worked through how new, more desirable aspects can be further institutionalised to the year 2050 and explored interactions between options.

The outputs of the co-creation workshops were collated in the form of posters and discussion notes and translated where required. This involved synthesising and categorising climate adaptation and mitigation options. This exercise produced a long list of adaptation and mitigation options (150+ per case study). These lists were prioritised to ensure they were feasible to take forward for further evaluation through consultation with 1) case study partners to determine which were highest priority for implementation according to their local priorities in the case study and 2) sectoral impact modellers to ensure that they were possible to evaluate for the impacts on various criteria, including contributions to adaptation and mitigation. The final lists were recirculated to case study partners for final validation.

2.3 Analysis of climate resilient pathways for opportunities for integration

The adaptation and mitigation options were developed using the conceptual framework and approach described in Section 2.1 and 2.2 were analysed to identify opportunities for integration across scales, sectors, societal domains and logics of change. The final lists of adaptation and mitigation options included several options that could not be quantitatively evaluated for one or more indicators but were high priority for case study partners, necessitating a semi-quantitative, mixed method approach. The analysis was done in two steps: 1) analysing the distribution of options generated that *target* adaptation, mitigation or both agendas and 2) evaluating the contribution of these options on adaptation and mitigation *outcomes*.

Analysis of the distribution of options targeting adaptation, mitigation and both agendas

Adaptation and mitigation options for each of the five case studies (i.e., across different *scales*) were categorised into sectors and societal domains. Options in the strategic pathway (i.e., from the policy review) were categorized, clustered and summarized according to the list of *sectors* and *societal domains*. Options from the adaptive and transformative pathways (i.e., workshops) were categorised according to these same *sectors* and *societal domains* for which they were developed in breakout groups. This categorisation was subsequently validated by a researcher.

Options were designated to *logics of change* according to the pathway in which they were developed. This choice was validated by a qualitative analysis of the workshop reports, examining how participant contributions aligned with the breadth and depth of change. We coded each intervention according to its breadth (degree of cross-sectoral scope) and depth of change (degree of systemic leverage following Abson et al.'s (2017) adaptation of Meadows' (1999) leverage points framework). Details of the coding framework and procedure are provided in Table S2 and S3. This validation showed that the session using a transformative logic generated more contributions associated with deeper leverage points (i.e., system design and intent) and greater breadth (i.e., system-wide) than the session following an adaptive logic. This suggests that the methods selected reflected the intended logics of change, providing an important foundation to justify further analysis.

Options targeting adaptation, mitigation or both agendas were designated initially in workshop reports and were then validated independently by two researchers. The total number and

distribution of options targeting adaptation, mitigation, and integrated measures were calculated and visualised for each case study (scale), sector, societal domain and logic of change.

Evaluation of the contribution of options on adaptation and mitigation outcomes

The evaluation of contributions to adaptation and mitigation outcomes was done using a mixed methods approach. All of the adaptation and mitigation options were evaluated for both adaptation and mitigation outcomes based on a number of indicators. Different sectoral experts evaluated different indicators using mixed qualitative and quantitative methods as needed: importantly, the rigour and level of detail provided in this assessment was adequate to identify opportunities for integration from a systemic view of climate action, but further detailed analysis would be required to guide implementation in specific contexts. This has been considered in the level of interpretation in the results and discussion. These scores are all reported in the DISTENDER Decision Support System (https://distender.dss.itti.com.pl/).

Summary of assessment

Contributions to adaptation were evaluated using a composite indicator that reflects 1) the influence of the option on coping capacity, i.e., the ability of people, institutions, organizations, and systems to address, manage, and overcome adverse conditions using available skills, values, beliefs, resources, and opportunities [39] and 2) the influence of the option on sectoral adaptation indicators, including reduction of human health impacts due to air quality, reduction of excess mortality due to heat, reduction in hydrological drought hazard, reduction in flood hazard, groundwater recharge, land use diversity, reduction in land use intensity, and impacts on biodiversity, ecosystem services and natural capital. The final adaptation score was taken as the mean of coping capacity in addition to all non-neutral influences of the option on sectoral impacts. These scores were then designated high, medium, low based on a distribution across the maximum and minimum of the dataset.

Contributions to mitigation were evaluated based on the combined effects of sectoral mitigation indicators, including increase in carbon storage, reduction in carbon emissions and reduction in energy demand. The final mitigation score was taken as the mean of all non-neutral influences of the option on these three components. The scores were then designated high, medium, low based on the range of scores of the dataset.

Coping capacity assessment

The influence of options on coping capacity was evaluated using an expert judgment to semi-quantitatively assess how implementation of the proposed options would influence human, social, manufactured and financial capitals [40]. Five researchers from different disciplines independently provided informed judgments and justifications regarding the direction and magnitude of expected influence on change in each capital due to implementation of the options (high positive, low positive, none, low negative, high negative). Each judgment was made by at least two researchers, informed by a baseline of the current distribution of these capitals over the spatial extent of each case study. Judgments from multiple researchers were aggregated based on the level of agreement, assigned a level of uncertainty and validated by case study partners. The overall coping capacity score was calculated as the mean value of all capital indicators on a common five-point Likert scale (high negative to high positive impact).

Sectoral indicator assessment

Different sectoral experts evaluated sectoral adaptation and mitigation indicators. The aim was to provide a score for the influence of each option on each indicator on the same five-point Likert scale (high negative to high positive impact) assuming maximum implementation. All experts first categorised the options regarding whether they would have a *potential effect* or *no effect*. Those that had no effect at all were assigned as neutral. Those that had potential effects were further categorised into i) non-modellable and ii) modellable options.

The influence of non-modellable options was evaluated using a targeted literature review to support the assessment, combined with expert assessment of at least two experts for each indicator. The choice of suitable literature was determined by the expert and addressed the transferability of the literature finding to the case study. Review papers were given priority over individual studies. If no suitable literature was available or found, options were evaluated based on expert assessment. Options were scored accordingly and assigned a level of uncertainty, depending on the supporting information available for the assessment.

For some sectors, modellable options were evaluated quantitatively by the relevant sectoral experts. The modelling method used for each indicator is summarised in Table 2. The full approach for modelling these sectoral impacts is detailed in Deliverable 5.1 (State of the art impact models: *ref to become available during review*).

Table 2: Summary of sectoral adaptation and mitigation indicator for modelled options

	Sector	**Indicator**	**Modelling approach**
Adaptation	Air quality & health	Human health impacts due to air quality	Estimation of air quality impacts (based on URBAIR® second generation gaussian model) Health impacts (based on concentration-response functions)
	Air quality & health	Reduction of excess mortality due to heat	
	Water	Hydrological drought hazard	None
		Reduction in flood hazard	
		Groundwater recharge	
	AFOLU	Land use diversity	Quantification of changes of the proportion of land-use types
		Reduction in land use intensity	None
		Impacts on biodiversity, ecosystem services and natural capital	
Mitigation	Air quality & health	Reduction in emissions	Estimation of emissions change (based on URBAIR® second generation gaussian model)
	AFOLU	Carbon sequestration	Yield-SAFE model's biomass growth simulations
	Energy	Reduction in energy demand	None

Air quality and health indicators were evaluated using the URBAIR® second generation gaussian model assuming a maximum implementation rate under common assumptions of the background socio-economic and climate scenario (SSP3-RCP7.0). Options considered to have an effect on these

indicators and to be modellable were translated into an emission reduction potential, assuming a high implementation rate, for both air pollutant and GHG emissions (i.e., emissions estimation based on activity change – e.g. reducing private cars in urban areas). Air quality and health impacts were estimated to inform the scoring of the respective strategies. Almost all strategies were assessed as a neutral to high positive effect.

Water indicators were scored by literature review or expert assessment and were not modelled. Indicators were interpreted as reduction in hydrological drought hazard (Change of river discharge in the 100-yr event of 21-days mean low-flow), reduction in flood hazard (Change of river discharge in the 100-yr event of 1-day mean high-flow) and groundwater recharge (Change of groundwater recharge). A standardised approach was used to translate a percentage of change to the indicator (as given in literature) to the common Likert scale.

AFOLU indicators were evaluated in different ways. Reduction in land use intensity and impacts on biodiversity, ecosystem services and natural capital were estimated by using literature review and expert judgment. The influence of options on land use diversity was calculated based on the changes of the proportions of different land-use types within the case studies, with higher values indicating more varied, evenly distributed uses. Estimates for carbon sequestration in above-ground biomass were obtained from the Yield-SAFE model [41] following the methodology in [42,43] to convert fresh timber volume to dry timber mass, to timber carbon, to CO_2 equivalent. Only standing timber for long-term utilisation was considered.

Energy demand was evaluated using literature review and expert judgment. Sectoral experts investigated the possibility to model options using a regression-based model approach that were already parameterised for each case study, but none were modellable.

3. Results

3.1 Distribution of options targeting both adaptation and mitigation

Each of the strategic, adaptive and transformative climate resilient pathways in five case studies yielded a wide range of adaptation and mitigation options. This included 75 options in Austria, 64 options in Dehesa and Montado, 55 options in Guimarães, 64 options in the Northern Netherlands and 75 options in Metropolitan City of Turin. The full list of options can be accessed in a Decision Support System from the DISTENDER project (https://distender.dss.itti.com.pl/), which creates ordered lists of adaptation and mitigation options based on performance against multiple indicators, including and beyond adaptation and mitigation.

The options are distributed across the dimensions of logics of change, scales, societal domains and sectors as shown by the size of the dots and number of options indicated in Figure a-d. Descriptive statistics of the distribution of options targeting adaptation, mitigation or both agendas are also depicted in Figure a-d.

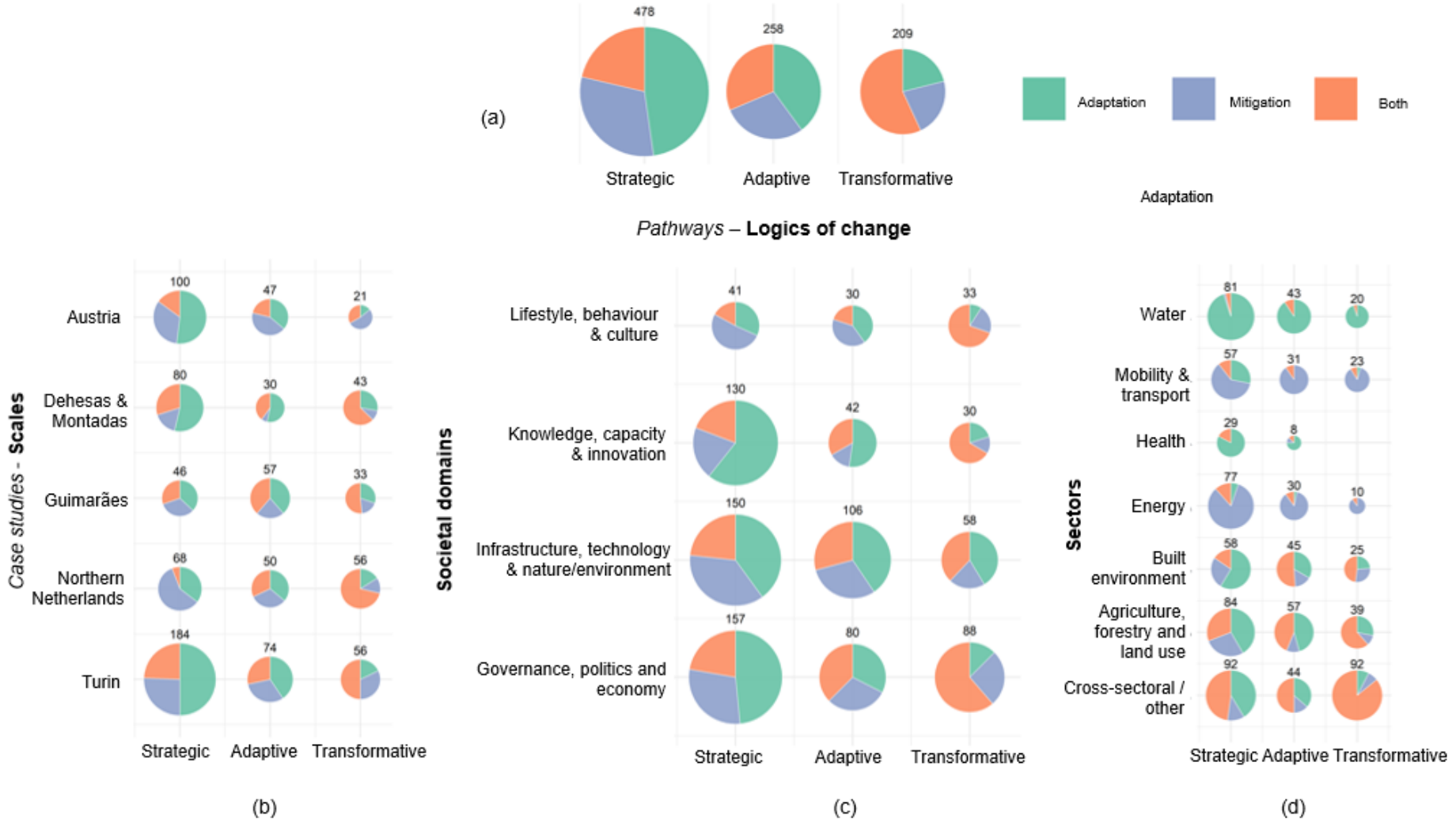


Figure 4: Proportion of options proposed that target adaptation (green), mitigation (blue) or both, i.e., integrated (orange). It shows the distribution of options according to (a) different logics of change (pathways), (b) scales (case studies) and logics of change, (c) societal domains and logics of change, (d) sectors and logics of change.

Across logics of change

There are opportunities for integration – i.e., where an option explicitly *targets* both adaptation and mitigation – across all three logics of change, with distinct, high-level patterns emerging (Figure 4a). First, the strategic logic (i.e., from the policy review) has a significantly higher proportion of options targeting adaptation, with shares becoming smaller in the adaptive and transformative logics (i.e., from the workshops). Second, the transformative logic has a significantly higher proportion of options targeting integrated solutions than the strategic and adaptive logic. This finding is also reflected in the distribution of options across scales (Figure 5b), societal domains (5c) and sectors (5d).

Across scales

Across the case studies at distinct scales (Figure 4b), the distribution of options targeting adaptation and mitigation follows largely the same trends as Figure 4a, with distinct policy priorities in each case study but no clear pattern across cases at the same scale (e.g., regions or cities). In most case studies, the strategic logic contains significantly more options targeting adaptation (Austria, Dehesa and Montado and CMTo). The Northern Netherlands and Guimarães differ, with the Northern Netherlands dominated by mitigation and Guimarães having a fairly even split across priorities. The adaptive logic sees a slightly more balanced distribution of options, except for Dehesa and Montado where the share of options targeting mitigation shrinks significantly. The transformative logic sees a significant higher share in options targeting both agendas, with Dehesa and Montado and the Northern Netherlands showing highest shares. Austria is the exception, with the distribution of options in the transformative logic differing only marginally from the adaptive logic.

Across societal domains

Across societal domains in Figure 4c, the distribution of options targeting adaptation, mitigation and both (i.e., integrated) are similar in the strategic and adaptive logic. In the transformative logic, the lifestyles, behaviour and culture (LBC); knowledge, capacity and innovation (KCI); and governance, politics and economy/wellbeing (GPE) domains show a significant proportion of options targeting both agendas. Integrated options related to GPE are the most numerous, such as implementing coherent mandatory standards for adaptation and mitigation, improving the accessibility and efficiency of permit procedures and financing for implementing adaptation and mitigation measures, and transforming the economy based on circular economy principles.

Integrated LBC options are complementary but fewer, such as launching campaigns that promote more conscious consumption and active citizenship, shifting mentalities about urban-rural migration to make rural living more attractive, and addressing polarisation of news media about sustainable lifestyles. Examples of KCI options targeting both agendas include establishing open science hubs that make information easily accessible and implementing a curriculum that teaches children nature skills and restorative practices. While less in proportion than the other societal domains, opportunities exist in ITE measures, including developing green islands as laboratories for the development of self-sufficient communities, pursuing the conservation of the nature and cultural values and implementing standards for green roofs and green facades in new construction.

Across sectors

Sector-specific findings (Figure 4d) surface clear patterns. The water sector is highly focused on adaptation across all three pathways, though options targeting both agendas exist, such as creating sponge cities that use nature-based solutions to retain rainwater and recharge aquifers, and

implementing widespread nature restoration expansion. Similarly, the AFOLU sector is largely focused on options targeting adaptation alone or both agendas, with numerous integrated options including cultivating abandoned land and forest gardens, developing and disseminating best practice guidance for climate resilient forestry and agriculture on mountain farms, and implementing natural climate buffers through widespread use of green infrastructure. The built environment also focuses on adaptation, with significantly more integrated options in the adaptive and transformative logics. Examples include unsealing urban soil, increasing green areas and ecological connectivity, and implementing passive building, nature-inclusive, and climate-adaptive building principles.

In contrast, options proposed for the mobility/transport and energy sectors largely target mitigation due to their significant role in the energy transition. Still, opportunities for integration exist: for example, digital transformation of the transport sector and mainstreaming resilience and sustainability objectives into local public transport projects were seen to promote both agendas. In the energy sector, mitigation options are accompanied by more integrated strategies than adaptation, such as optimising interactions between electricity generation and consumption, including by reducing internal loads that help avoid overheating in warmer temperatures. Options specifically addressing the health sector were few because health featured less significantly in workshops as it was primarily considered as an outcome of options in other sectors (e.g., positive impacts of options on reducing the health impacts of changes in air quality, see section 2.3).

Cross-sectoral options yielded significantly more opportunities to target adaptation and mitigation than any other sector, reflecting how system-level changes in governance, politics and economy or sustainable lifestyles and behaviour change contribute to both agendas. Examples include strengthening knowledge transfer across sectors and between science and policy, supporting innovation in the industrial sector related to climate resilience by financing start-ups, small enterprises and young researchers, developing short distance transport and localised agri-food supply chains, and ceasing financing of infeasible technological solutions for adaptation and mitigation.

3.2 Evaluation of contributions to adaptation, mitigation and integration outcomes

The findings of the evaluation of the options on adaptation and mitigation *outcomes* are summarised in Figure . These findings are interpreted across logics of change, scales, societal domains and sectors. Across the board, the patterns across these findings are fewer and less distinct than in section 3.1. However, investigating options with medium to high contributions to both adaptation and mitigation reinforced findings from section 3.1 while also highlighting additional opportunities for integration that did not emerge from the analysis in section 3.1. In these cases, options targeting one agenda (i.e., adaptation *or* mitigation) had the potential for positive outcomes for both adaptation and mitigation. This section focuses more on providing individual examples of new opportunities to complement the high level patterns and examples from section 3.1.

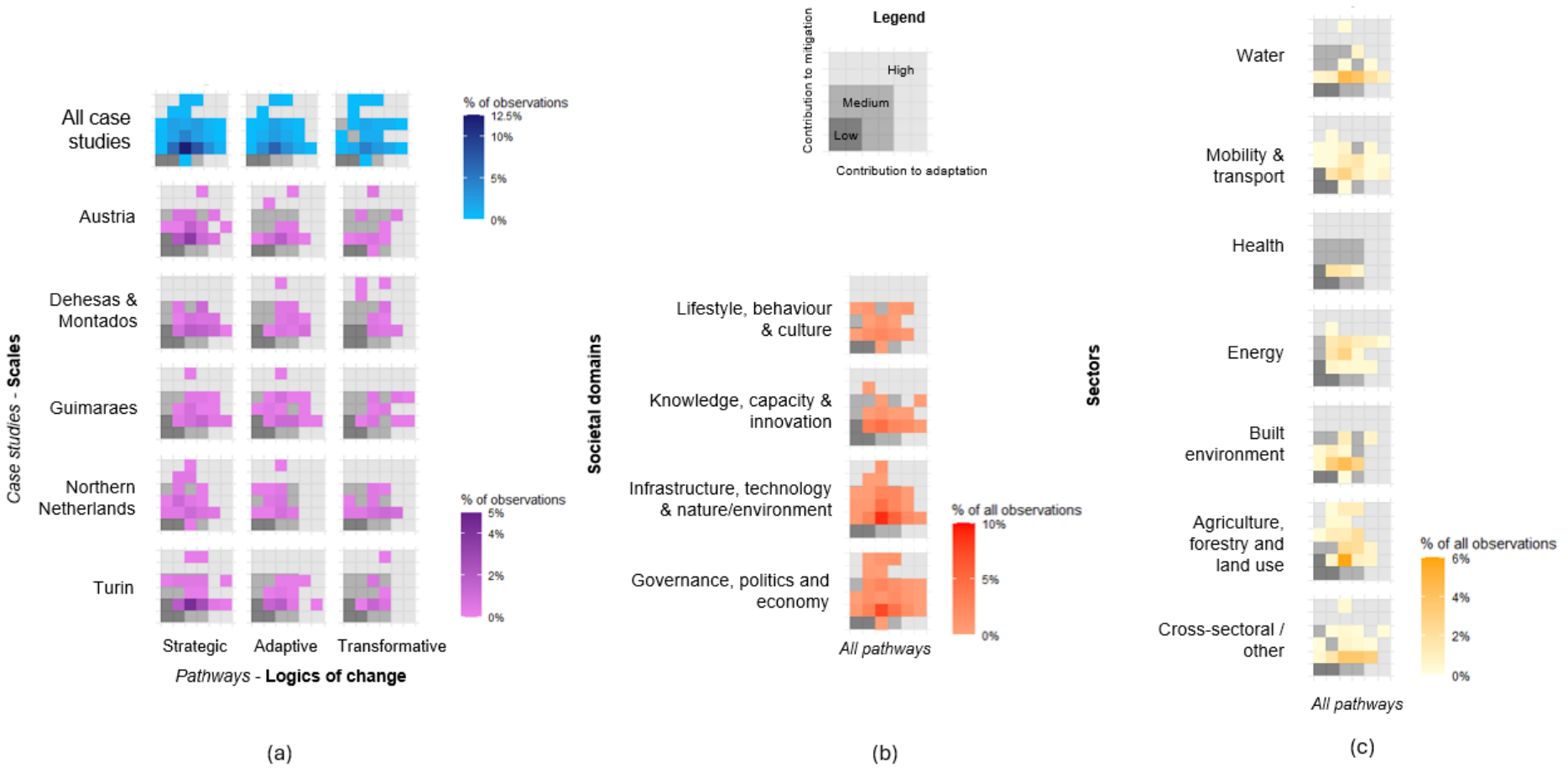


Figure 5: Contributions of all adaptation and mitigation options from Figure 4 to adaptation and mitigation outcomes, on a scale of low, medium and high in each box (horizontal scores adaptation; vertical scores mitigation). Colour shading shows the percentage of all observations (for each sub-figure a, b and c) in each square for the given combined adaptation x mitigation score, so options closer to the top right of the square are assumed to have highest contributions to integration of adaptation and mitigation. (a) shows the contributions per case study (row), representing multiple scales, and per pathway (column), representing different logics of change sector across all three pathways, (b) shows the contributions per societal domain for all three pathways, (c) shows the contributions per sector for all three pathways.

Across logics of change

There are opportunities for integration – i.e., where an option has the potential to produce medium to high positive *outcomes* for both adaptation and mitigation - across all three logics as shown in Figure 5a. All three pathways show the highest density of options with medium contributions to adaptation and low contributions to mitigation. Unlike the clear patterns across logics of change in Section 3.1 - where the transformative logic showed more opportunities for integration - there does not appear to be a clearly discernible pattern.

Across scales

For the national case study of Austria, findings highlight opportunities for integration focusing on soil health, improving agricultural landscape resilience and implementing binding mainstreaming regulations for adaptation and mitigation across sectors. Options to create 15-minute cities and decentralise energy participation that target mitigation showed unexpected opportunities for integration due to their positive impact on coping capacity through improving social and human capital.

In the region of Dehesa and Montado, findings highlight that shifting food consumption patterns, integrated and adaptive agricultural, livestock and forest management, and embedding adaptation requirements into energy-sector codes and standards offer the greatest integration opportunities across pathways. Highest scoring adaptation measures showed limited mitigation effects, reflecting the region's focus on soil and water conservation. In contrast, several mitigation-oriented options such as ecosystem service subsidies or improved carbon storage measurement also generated adaptation benefits by supporting community coping capacity. In the other regional case study of the Northern Netherlands, findings show that transforming the food sector and enhancing biodiversity in agriculture and water management contribute to integration. Interestingly, top adaptation measures, such as shifting farms to grow hemp or lupin, were assumed to be neutral for mitigation.

In Guimarães, findings highlight that agriculture and forest management, creating car-free, walkable cities, and shifting to a circular economy and passive house standards in buildings offer the greatest opportunities for integration. In contrast to regional cases, highest contributions to adaptation, such as improving the robustness and sustainability of urban public transport, also positively influence mitigation. In CMTo, findings show that options such as redeveloping industrial abandoned or environmentally degraded areas, implementing renewable and decentralized energy systems, and coordinating adaptation to heat waves offer the most significant opportunities for integration.

Across societal domains

There are opportunities for integration across all four societal domains as shown in Figure 5b. All four societal domains show a high density of options with medium contributions to adaptation and low contributions to mitigation. Significantly more contributions to integration of adaptation and mitigation appear in the societal domains infrastructure, technology, and nature/environment (ITE); and governance, politics, and economy/wellbeing (GPE).

In ITE, several nature-based options offer opportunities for integration due to their combined influence on carbon storage in soil and forests, reduced emissions or energy demand from changing practices (e.g., in agriculture) and the role of ecosystems in providing buffers to climate extremes such as floods and droughts. Examples include adaptation measures such as regenerative agrosilvopastoral systems and increased water retention and soil moisture for drought resilience.

Some hard infrastructure and technology-driven options also offer opportunities, such as efforts to decentralise energy systems, which offer greater resilience to extreme events.

In GPE, opportunities for integration are expansive, crossing institutional, economic and policy-oriented domains. Examples include establishing democratic energy governance with an active role for consumers or transforming toward a circular economy. Opportunities also exist in redeveloping abandoned lands and implementing subsidies for ecosystem services, water, and carbon retention, as these contribute to resource efficiency and resilience in ways that address both agendas.

Across sectors

There are opportunities for integration across all sectors, as shown in Figure 5c. The highest density of options across sectors are clustered around low contributions to mitigation and medium contributions to adaptation. Sector-specific preferences for adaptation versus mitigation exist and reinforce some findings from Section 3.1, though more opportunities for integration in the energy sector emerge.

In the water sector, opportunities for integration relate to nature and land use, reinforcing findings from section 3.1. The highest scoring adaptation measures having little to no impact on mitigation, such as better drainage, storage, treatment and containment of water as buffer periods. There are many related opportunities for integration in the AFOLU sector, such as land management practices, afforestation and reforestation. Several opportunities relate to incentives for farmers and land managers to adopt more climate friendly practices, such as a certification scheme for positive impacts on adaptation and mitigation for agricultural producers and forest managers.

In contrast, the mobility and transport sector offers opportunities for integration unexplored in section 3.1 due to the role of community infrastructure in reducing transport demand and improving social and human capital. Examples include diversifying and shortening supply chains and creating better long distance public transport connectivity. Similarly, in the energy sector, new opportunities for integration relate to options that decentralise and democratise renewable energy systems. This is mirrored in the built environment sector, where opportunities for integration focus on improving the energy efficiency and sustainability of buildings and mobility infrastructure. In the health sector, key priorities were focused on addressing heat stress and air pollution, with opportunities to integrate health priorities across other sectors.

Cross-sectoral options offer many opportunities for integration, primarily in economic transformation, lifestyle and behaviour shifts, financial and tax incentives, policy mainstreaming and binding regulations, reinforcing findings from section 3.1.

4. Discussion

This paper first aimed to adopt a systemic view of climate action, enabling the co-creation of climate resilient pathways that include adaptation and mitigation options across multiple dimensions of climate action. A novel transdisciplinary methodology was developed and tested to do so, building on prior studies exploring logics of change underpinning scenarios for climate resilience [29] and leveraging diverse approaches for exploring future scenarios and pathways in transdisciplinary research with local stakeholders [31,44]. The final pathways are expansive, comprised of between 55 and 75 options in each case study, spanning seven sectors and four societal domains (section 2.1). This contribution offers a rich set of options to inform future research and action within the case

studies, which can also inform and inspire the implementation of similar methodologies in other contexts.

This paper also aimed to use this systemic view of climate action to analyse and evaluate the pathways for opportunities for integration. This allowed us to identify broad patterns and examples regarding opportunities for integration beyond narrow sector- and intervention-specific findings, with significant implications for policy and practice. This was done in two ways. First, opportunities for integration were found where an option explicitly *targets* both adaptation and mitigation (section 3.1), yielding important patterns. A key finding is that greater opportunities for integration surfaced in options underpinned by a transformative logic, reinforcing the need to address more fundamental changes and systemic societal drivers underpinning the climate crisis to support integration [45,46]. This finding also reinforced the growth of novel methodologies such as ours to explicitly leverage transformative logics in defining integrative options [47,48]. Additionally, the societal domains of GPE, KCI and LBC societal domains had higher proportion of options targeting both agendas than the ITE domain, reinforcing the importance of looking beyond technical fixes and sector-specific interventions to the areas of good governance, sustainable lifestyles, education, economy and culture [49,50]. Cross-sectoral options had significant opportunities for integration, highlighting the need to break down entrenched policy siloes [51] and mainstream climate as a cross-cutting issue across all administrative levels of governance [52,53]. Opportunities for integration in the AFOLU and built environment sector reveal the importance of nature-based solutions and shifting land management as core climate strategies, offering win-win synergistic options between adaptation and mitigation [18,54]. This finding further reinforces the potential to address the dual climate and biodiversity crises as a nexus rather than treating them in isolation [55,56].

The second approach sought additional opportunities for integration where an option scored medium-to-high in its contributions to both adaptation and mitigation *outcomes* (section 3.2). Importantly, this assessment compared different outcomes on a common semi-quantitative scale using a mixed methods approach, combining sectoral modelling, literature review and expert judgment as needed to identify opportunities for integration that can be further investigated with detailed quantitative evaluations. Overarching patterns across logics of change were less distinct than the former analysis (section 3.1). However, this revealed an important finding: options targeting adaptation or mitigation exclusively still had unexpected synergies with the other agenda. For example, options in the mobility and energy sectors primarily targeted mitigation but had unexpected synergies with adaptation. Mitigation options including establishing decentralised and community-led energy systems or creating car-free, 15-minute cities [57,58] were seen to improve community infrastructure and the social and human capital required to respond effectively to future climate risks. This reinforces previous studies that showed how adaptation policies can “piggyback” on mitigation [59] and aligns with wider critiques of technocratic and techno-optimistic framings in climate governance that restrict the policy solution space [60,61]. There is a need to actively support measures that facilitate community building and engaged citizenship to identify integrative options and strengthen climate resilience [62,63].

The analysis was conducted across five case studies representing different scales. No significant patterns in opportunities for integration emerged across common scales, such as the two cities (Guimarães, Metropolitan City of Turin) or the two regions (Dehesa and Montado, Northern Netherlands). This finding signals the need for more case studies to draw trends, but more

importantly highlights the role of local knowledge and context in operationalising calls for integration of adaptation and mitigation [64]. As a rural landscape focused on agroforestry with already high ecological value, Dehesa and Montado shows a much stronger emphasis on adaptation and integrated priorities than mitigation, possibly due to its climate vulnerability and limited potential to increase mitigation potential. In contrast, the distribution of options in Austria showed a preference for mitigation rather than integrated options, potentially due to the national scale that is bound to EU mitigation targets, which may have less direct oversight over more diffuse and heterogeneous adaptation measures implemented by municipalities and provinces. Individual examples of opportunities for integration highlight the role of local context further. For example, the culture and economy in the Northern Netherlands is tied to agriculture with ongoing tensions between intensive farming and conservation (e.g., peatlands), explaining why transformations in the food sector emerged as one of the highest potential options for integration. Capacity building among policy makers and practitioners can help leverage and contextualise findings of this study, and future research is required to uncover these context-driven factors influencing integration opportunities.

The transdisciplinary, mixed methods approach adopted in this study enabled significantly more systemic and novel insights than a previous approaches reflecting single disciplines, sectors or priorities. Co-creating three pathways underpinned by strategic, adaptive and transformative logics was particularly crucial for surfacing diverse options and revealing compelling patterns including the role of cross-sectoral actions and transformative logics. However, the approach had limitations. Development of the strategic pathway focused on policies formulated in documents, which does not reflect which have been or will be implemented in the future. The options emerging in the adaptive and transformative pathways were also shaped by workshop design, participant expertise and perspectives, and quality of facilitation, including responsiveness participant needs. While the part of the workshop aligned to the transformative logic surfaced more transformative conversations between participants (section 2.3), further work is needed to understand how this potential translated into the final prioritised strategies. Importantly, the benefits of transdisciplinary research extend beyond knowledge outputs to mutual learning across researchers and participants [65]: future research can build on this work to sustain and evaluate participant ownership and learning and steward more integrated thinking.

The evaluation of options used a mixed methods approach, which was useful for understanding high-level patterns but limited by a standardised assessment across cases. This meant that highly heterogeneous options spanning different scales and sectors were evaluated on equal terms. Future research could define quantified ambition levels for each option, enabling more precise assessment of adaptation and mitigation outcomes and better tailoring to specific contexts. Involving additional experts beyond the core team could strengthen the evaluation process. In that sense, it is important to stress that the methodology can be replicated but future iterations can reinforce its impact.

5. Conclusion

This study applied an innovative new method to identify opportunities for integration from a systemic view of climate action in five diverse European case studies. To do so, we co-created climate resilient pathways in five diverse case studies across Europe, comprised of an expansive range of adaptation and mitigation options. We systematically analysed and evaluated these pathways to identify opportunities for integration across an expansive range of societal domains, sectors, and logics of change, revealing important patterns. The greatest opportunities lie in cross-sectoral actions

and options underpinned by transformative logics, reinforcing the importance of systemic change in institutional, economic and cultural paradigms. Nature-based solutions and land management practices provide dual benefits by enhancing climate resilience while sequestering carbon. Additionally, surprising findings emerged in options targeting adaptation *or* mitigation provided benefits for both: for example, mitigation measures that improve community infrastructure and democratise energy systems generate adaptation co-benefits by strengthening social and human capital.

This study responds directly to calls from the IPCC to produce evidence supporting the integration of adaptation and mitigation and addressed a methodological gap by developing and testing a novel transdisciplinary approach. Our findings open up multiple avenues for future research. First, other contexts around the world can leverage our methodological approach to uncover opportunities for integration, expanding to other contexts or investigating other dimensions. Second, further research is required to unpack the role of transformative logics and cross-sectoral interactions in supporting integration. To do so, the IPCC and climate research community can be inspired by the biodiversity research community to leverage the rich scholarship in the social sciences and humanities about transformative change [25] and the unique insights and opportunities that emerge using a nexus approach [66]. Third, further research can more rigorously investigate the unexpected finding that mitigation options (e.g., car-free cities or democratised energy systems) create enabling conditions for adaptation at local scales, potentially uncovering opportunities for more efficient and synergistic planning and coordination. Finally, this study scratched the surface of scale considerations in the integration agenda. Future research could systematically assess how the effectiveness and relevance of integrated options vary across scales, for example at national, regional, or local/municipal levels to better capture scale-dependent dynamics to inform targeted policy design.

Accelerating action toward a climate-resilient future requires both a rapid transition away from fossil fuels and effective adaptation to the impacts of climate change. Generating evidence to inform decision-making demands a transdisciplinary approach that cuts across traditional policy and research silos, providing systemic insights capable of addressing complexity and delivering actionable solutions. Overall, the study confirmed that integrated options exist in interesting ways across different sectors, societal domains, scales and logics of change, complicating their assessment using conventional sectoral metrics. Transdisciplinary research is required to carefully align qualitative and quantitative methods across disciplines and perspectives to align co-creative pathways and modelling frameworks capable of capturing complexity. Opening the process to local stakeholders is also an opportunity to increase the ownership and the societal acceptance of the policies that can derive from the process outcomes. We hope this contribution encourages further research and action that bridges knowledge and action to inform climate resilient solutions.

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