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Lessons from a decade of adaptive pathways studies for climate adaptation

Marjolijn Haasnoot[a,b,*], Valeria Di Fant[a,b], Jan Kwakkel[c], Judy Lawrence[d]

[a] Deltares, Department of Climate Adaptation and Disaster Risk Management, Delft, the Netherlands
[b] Utrecht University, Department of Geosciences, Utrecht, the Netherlands
[c] Delft University of Technology, Department of Technology Policy Management, Delft, the Netherlands
[d] Climate Change Research Institute, School of Geography, Environment and Earth Sciences, Victoria University of Wellington, Wellington, New Zealand

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ABSTRACT

Adaptive pathways planning is an approach that maps the solution space over time to inform decision making under uncertainty. Since its first applications to climate change adaptation in the '10s several studies and practical applications have used and extended the approach and discussed its benefits, limits, and complexity. What have we learned from a decade of adaptive pathways studies? This paper elaborates lessons learned on the use, value and weaknesses of adaptive pathways approaches for decision making using a set of guiding questions related to the decision context, the methods used, and contributions to decision making. Based on our experience and literature review, we find that: a) adaptive pathways analyses have been applied widely and are moving from theory to practice; b) an adaptive pathways analysis can be tailored and typically follows a staged approach; c) methods include narratives, impact models, and stakeholder participation tools; d) the complexity of adaptive pathways as a result of multiple actors, values, hazards, and actions at various scales for different purposes is a challenge, and this is increasingly considered through various extensions and combinations with other approaches. Ways forward to address weaknesses and current challenges include: accounting for coevolution between multiple actors across different scales (e.g., through interactive and multilevel pathways) and combining an adaptive pathways analysis with visioning and backcasting approaches for transformative adaptation and operationalizing climate resilient development pathways. To enable further applications in practice, it is important that experiences are shared and governance issues (e.g. long-term planning and funding) addressed.

1. Introduction

Societies must make adaptation decisions in the face of observed climate change, expected near-term impacts, and deep uncertainty about future impacts, including those arising from compounding and interacting climate extremes and climate tipping points. Uncertainties about climate change impacts are increasingly acknowledged in adaptation decision making. Building upon the experience in military planning (Kahn and Wiener, 1967) and business development (Bradfield et al., 2005; Van der Heijden, 1996), the use of alternative future scenarios has become widely embedded in environmental planning and climate change mitigation and adaptation since the 1990s (Alcamo, 2008; Hulme and Dessai, 2008; Moss et al., 2010; Rothman, 2008). More recently, as complexity of systems affecting policy has evolved, scenario use has been complemented with approaches for decision making under deep uncertainty (DMDU) (Marchau et al., 2019; Walker et al., 2013). Deep uncertainty exists when there is a lack of knowledge that cannot be reduced and/or a lack of agreement about the future and its uncertainties, probabilities, and consequences, and about how to value outcomes (Lempert, 2013). DMDU approaches typically stress-test the current situation and alternative strategies against a range of possible futures (Marchau et al., 2019). One DMDU approach is Dynamic Adaptive Pathways Planning (DAPP; Haasnoot et al., 2013, 2019a). Pathways describe trajectories over time and in the context of DMDU they are used to build in flexibility to deduce lock-in of policy responses and resulting path dependency.

The concept of pathways has evolved from the application of scenarios and has been used in other fields for decades (Eisenhauer, 2016; Rosenbloom, 2017). In climate science, *scenario* pathways are used to describe trajectories of climate and societal change to support consistent futures analyses that can inform policy (e.g., the climate scenario framework used by the IPCC (O'Neill et al., 2020) or the storyline approach of Shepherd et al. (2018). The pathways concept has also been used to describe sequences of measures referred to as *policy* pathways or

* Corresponding author at: Utrecht University, Department of Geosciences, Vening Meineszgebouw A, Princetonlaan 8a, 3584 CB Utrecht, the Netherlands.
E-mail address: m.haasnoot@uu.nl (M. Haasnoot).

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adaptive pathways. For example, in sustainable development research, pathways describe alternative development trajectories linked to normative goals (Eisenhauer, 2016; Frantzeskaki et al., 2019). In transition research, pathways describe a trajectory to a new sustainable and/or low-carbon future state, different from the current state (e.g., Geels and Schot, 2007; Loorbach and Rotmans, 2006; Van der Brugge et al., 2005) with the STEPS approach as a prominent method (STEPS stands for Social, Technological and Environmental Pathways to Sustainability; Leach et al., 2007; Stirling, 2015). STEPS sees pathways not only as alternative trajectories of measures, but also of knowledge and change. More recently, the concept of climate resilient development pathways (CRDP) aims to inform policy making to achieve a climate resilient future for all, while acknowledging interactions between adaptation, mitigation, and development (Werners et al., 2021b; Schipper et al., 2022).

Adaptive pathways planning explicitly addresses decision making over time as conditions change and has been used mostly for climate change adaptation decision making (also referred to as adaptation pathways approaches), which is the focus of this paper. DAPP offers a stepwise analytical approach to explore alternative policy pathways and potential transfers between them, which informs the design of an adaptive plan (see Box) to address uncertainties in changing risks. This helps to break adaptation into manageable steps over time, starting with flexible near-term actions to avoid investing too much or too early, or locking in investments. Such a systematic approach, and its roadmap-like visualisation of the solution space over time, has appealed to decision makers to deal with uncertainty and the complexity of climate interactions with societal activities and values. As a result, it is increasingly being taken up by practitioners.

The foundational ideas underpinning adaptive pathways planning for climate change adaptation decision making are now over a decade old. In the Netherlands, the approach emerged from the desire to have a planning method that is less dependent on a specific set of scenarios, after a new generation of climate scenarios required changes in regulations and updating of existing adaptation plans (Haasnoot and Middelkoop, 2012). This led to the idea of identifying under what conditions new measures are needed (Kwadijk et al., 2010). These conditions (e.g. different sea levels) may occur earlier or later depending on the different scenarios used. After such conditions, alternative decisions and pathways are possible (Haasnoot et al., 2012, 2013). Similar thinking arose in the United Kingdom, where a decision-centred approach was developed that starts with the vulnerability of the system, instead of a scenario-centred approach, to deal with uncertainties in rates of sea-level rise (Ranger et al., 2013). Another group of researchers (Wise et al., 2014) emphasized the need to broaden the adaptive pathways approach to also include dynamic interaction between values, knowledge cultures and institutions. They focused on the descriptive narrative of adaptation as a process (Butler et al., 2014; Wise et al., 2014).

Since these foundational ideas, adaptive pathways approaches have been applied in many different decision contexts and application domains, both in practice and theory (see section 3.2). Given the urgency for adaptation consequent upon observed climate changes and their impacts globally (IPCC, 2022), it is timely to review what can be learned from these applications.

Previous adaptive pathways reviews have analysed a set of case studies and assessed pathways definitions, methods, and stakeholder participation (Bosomworth et al., 2017; Lin et al., 2017; Sparkes et al., 2023; Werners et al., 2021a). Building upon a survey among 13 adaptive pathways projects in Australia, Lin et al. (2017) conclude that many councils adopted the pathways approach in their decision making, but that the approach would benefit from stakeholder participation. In an editorial piece, Sparkes et al. (2023) conclude that more research is needed on how to include diverse social contexts and group needs, and on monitoring and evaluation. Werners et al. (2021a) found three clusters of pathways applications in 19 case study papers, namely, pathways oriented at performance-thresholds, at transformation or at a multi-stakeholder setting stressing the social and institutional components. Others have analysed adaptive planning case studies in general (thus not only pathways studies) for identifying barriers and enablers for implementation (Malekpour and Newig, 2020). A recent systematic bibliometric review and text mining study focused on the evolution of adaptive pathways approaches, highlighting scholarly networks and theoretical differences (Cradock-Henry et al., 2023). Considering previous assessments, there is room for a systematic review of what has been learned about the use and value of adaptive pathways approaches for decision making in a rapidly changing world with large uncertainties about climate change, impacts, adaptive capacity, societal changes and their coevolution.

This paper provides a synthesis of the use, value and weaknesses of adaptive pathways approaches for decision making based on a set of guiding questions on the context and purpose of their use, the methods used, and the contributions to decision making. This paper, for the first time, maps adaptive pathways applications globally and provides an overview and synthesis of its use in different policy domains, including various guidance documents, and draws out lessons on the contribution and value of adaptive pathways for decision making. The authors have drawn from their wide range of experiences in pathways applications and using DAPP as an analytical approach, both in theory and practice. Based on this experience and an extensive literature assessment and text mining, we have mapped applications and method development over the past 10 years (2013–2023) globally and identified critical lessons and ways forward to address weaknesses and improve and enrich adaptive pathways approaches and their implementation. With these lessons, we aim to guide future applications as well as research into the theoretical underpinnings of adaptive pathways approaches in this rapidly changing world, where climate change is happening faster than previously understood, while actions are often too incremental and implemented too slowly for reducing the risks to society. We therefore give specific attention to DAPP being an approach that supports decision making where risk is changing and there are deep uncertainties. We also aim to learn from the features of descriptive pathways studies— for example those that don't specifically consider the changing risk conditions and the need for near-term decisions to keep options open, or those that do not analyse alternative pathways, but do describe dynamic interactions between environment and society.

2. Methods

2.1. Purpose and data collection

To assess the use, development and value of adaptive pathways approaches for decision making in the past decade, we started our analysis with three highly cited foundational papers that introduced and reconceptualised the pathways concept to climate change adaptation (Haasnoot et al., 2013; Ranger et al., 2013; Wise et al., 2014). Using Scopus (August 2023), we downloaded all papers that cite any of these papers and indexed them by their DOI, discarding any papers without a DOI. This resulted in a dataset of 1442 papers.

Before analysing the papers, we created a subset by first selecting those papers that used the words 'pathway' and 'adapt' in the title, abstract, or keywords. This yielded 355 papers. Next, we scanned each paper based on the abstract, introduction and conclusion. We only kept papers that described: a) a pathways case study, b) methodological developments building on adaptive pathways, or c) a review of adaptive pathways literature. Papers that could not be accessed (six in total) were also discarded at this stage. A few additional papers were added through snowballing (26). The resulting subset contained 238 unique papers that were analysed in depth. To further assess the use of adaptive pathways approaches, we collected guidance documents incorporating an adaptive pathways approach from our network and experiences in the past decade, with a few added from Stafford-Smith et al. (2022).

2.2. Data analysis

For the data analysis, we proceeded in 2 steps. First, we used topic modelling and co-citation analysis to reveal the broader structure of all the papers that cited the three foundational papers. Second, we performed an in-depth systematic review of a subset of the papers and complemented this with experiences in practice. These two analyses offer complementary perspectives on the structure of the corpus.

2.2.1. Topic modelling and co-citation analysis

For the topic modelling, we analysed the title, abstract, and keywords through Latent Dirichlet Allocation (Blei et al., 2003) to reveal different topics. The number of topics is a user-specified parameter. We varied the number of topics from five to twenty. We settled on eight topics as this offered a reasonable balance between interpretable yet distinct topics, while being relatively robust to the stochastic nature of the Latent Dirichlet Allocation algorithm.

A co-citation network was created after making the citation

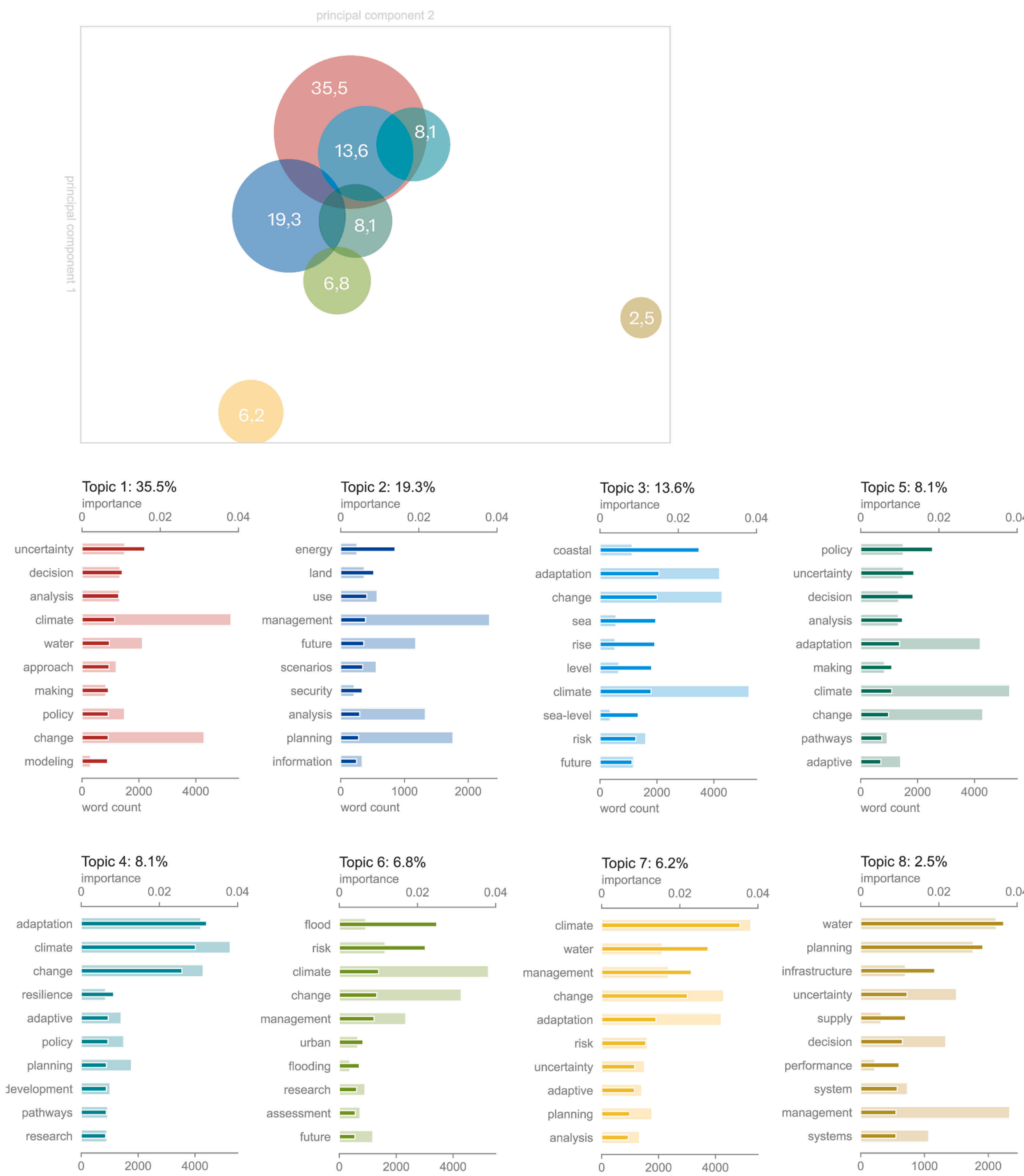

Fig. 1. Topic modelling results. The upper panel shows a principal components-based scatter plot of the topics. The size of the circle is proportional to the share of the topic in the overall assessed body of literature. The bar charts show, for each topic, the most important words (dark colour) and their frequency within the topic (light colour). Colours are consistent between the scatter plot and the bar charts.

consistent, focusing only on papers cited at least three times. To reveal clusters of papers that are frequently cited together, we used a community detection algorithm (Clauset et al., 2004; Newman and Girvan, 2004). Next, we identified, for each cluster, both the top five most frequently cited papers and the five papers with the highest eigenvalue centrality within the cluster. More details are given in the Appendix A.1.

2.2.2. Mixed method of literature assessment and experiences

Next, we used the filtered set of papers that explicitly use the terms 'pathway' and 'adapt' to do a more in-depth assessment. For this purpose, we coded these articles for three main questions (see Appendix A.2 for sub-questions):

1) For what purpose and where is an adaptive pathways approach used (including location, decision domain, theory/practice)?
2) How are adaptive pathways assessments done (including generation, visualisation, evaluation, and institutional arrangements?
3) How has the use of adaptive pathways approaches contributed to decision making?

To assess whether the approach has been used in practice and how it contributed to decision making, we used multiple lines of evidence: a) the assessment of the papers, b) an inventory of guidance informing practitioners, c) the authors' experience with applications in practice, and d) input from workshops with of practitioners and theorists. For the third question, we mostly drew from our experience, grey literature in accessible planning documents, complemented with an assessment of what the papers reported. The findings of the literature assessment were discussed and complemented with experience from participants at a session at the 2023 annual meeting of the Society for Decision Making under Deep Uncertainty and a workshop in March 2023 on ten years of pathways applications in New Zealand (Anonymous, 2023).

3. Results

3.1. Topic modelling and citation analysis

Fig. 1 shows the results of the topic modelling. The upper panel shows a principal-components-based plot of the topics where the size of the circle is proportional to the share of the topic in the overall corpus. To interpret the topics, the bar charts show the most important words and their frequency within a topic.

We find three large topics reflecting 14, 19, and 36 % of all the text together in the papers' title, abstract, and keywords. The other topics are small (less than 8 %). Topic 1 is a generic background topic on modelling and analysis for climate change adaptation in support of decision making, and planning. Note the high importance of 'uncertainty' relative to its lower frequency. Topic 2 is about energy and land use, which suggests a climate mitigation focus. Topic 2 also is close to but distinct from topic 1 as seen in the scatter plot. Topic 3 is about coastal adaptation and sea-level rise and overlaps with topic 1. Topic 4 is a broad topic about climate change adaptation planning with attention to resilience and

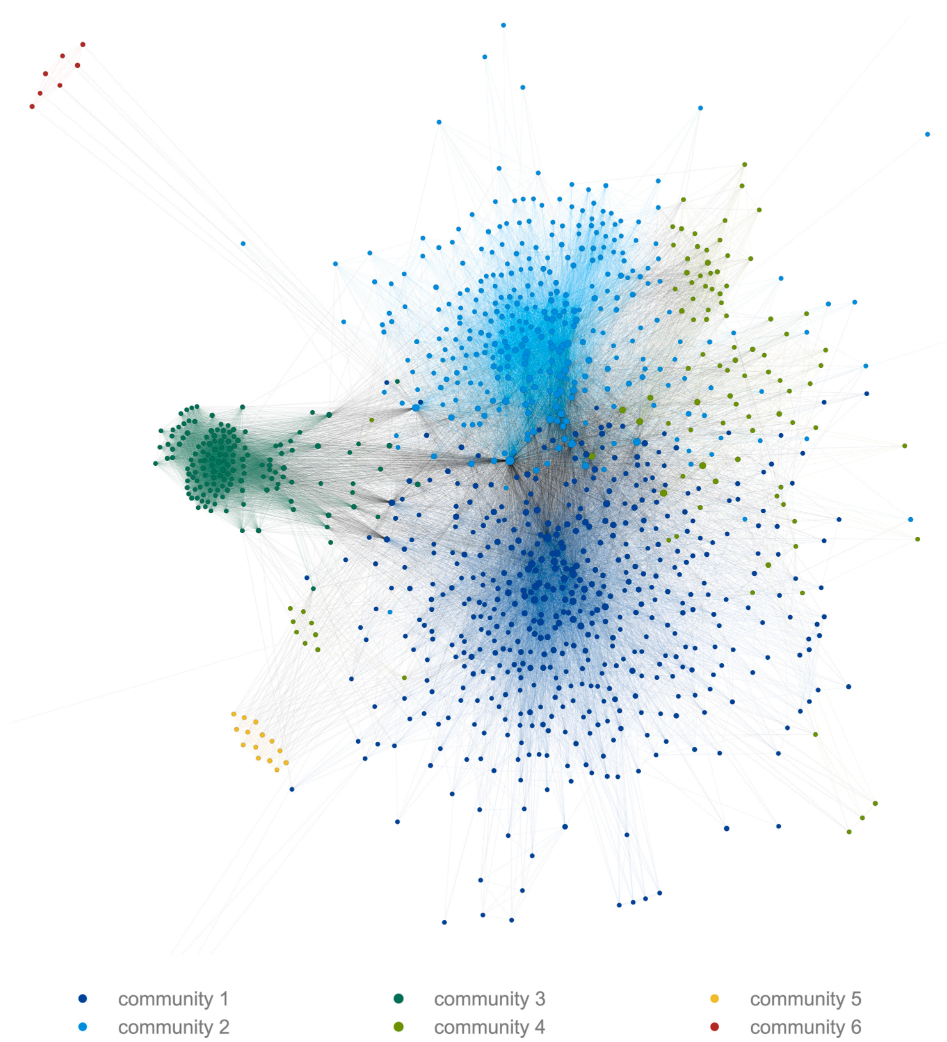

Fig. 2. Citation analysis results. Edges are scaled based on the number of co-citations. Nodes are scaled based on their total number of citations.

pathways, overlapping somewhat with topic 1. Topic 5 is a deep uncertainty topic with a focus on uncertainty, analysis, policy, and decision. Topic 6 is a flood risk topic, with specific attention to urban flood risk as indicated by the higher importance of 'urban' relative to its frequency. Topics 7 and 8 are the smallest and most distinct from the other topics. The distance of topic 7 from topics 1–6 suggests that this topic primarily focuses on water management and has a limited link to climate change adaptation. One plausible explanation is that adaptive pathways are discussed in the Integrated Water Resources Management literature. Topic 8 is a (water) infrastructure planning topic. The explanation for this topic is similar to topic 7, although its pattern of word usage is quite distinct.

Fig. 2 shows the results from the co-citation analysis. We identify six communities within the overall citation network based on the key (i.e., highest eigenvalue centrality in the network) and most highly cited papers. Community 1 is a generic climate change adaptation and climate resilience topic, including Wise et al. (2014) and Barnett et al. (2014) on adaptation; Pelling (2010) and Kates et al. (2012) on the need to move towards transformation; and Smit and Wandel (2006) with a foundational review on adaptation, adaptive capacity, and vulnerability. Community 2 is focussed on decision making under deep uncertainty and includes the pathways papers of both Haasnoot et al. (2013) and Ranger et al. (2013), but also DMDU methods papers on multi objective robust decision making (Kasprzyk et al., 2013) and Scenario Discovery (Bryant and Lempert, 2010), and papers linking DMDU and climate adaptation (Hallegatte, 2009; Lempert and Collins, 2007). Community 3 reflects a more social science-oriented perspective on adaptation. It includes papers such as Howlett and Rayner (1995, 2013) on policy subsystems, policy instruments, and patching and packaging in policy portfolio design; Bode (2006) on welfare mixes; Thelen (2005) on institutional evolution; Brugnach et al. (2008) on a relational understanding of uncertainty; and Swanson et al. (2010) who present various tools policymakers can use in practice when developing adaptive policies. Community 4 is focussed on sea-level rise, wherein Hallegatte et al. (2013) report on future flood losses for coastal cities; DeConto and Pollard (2016) on the contribution of Antarctica to future sea level rise; Nicholls and Cazenave (2010) discuss the impact of sea-level rise on coastal zones; Jackson and Jevrejeva (2016) present a probabilistic approach for regional sea level rise projections; Slangen et al. (2017) review global and regional sea-level rise projections; and Horton et al. (2015) focus on sea level rise and coastal storms for New York City. Communities 5 and 6, focus on social corporate responsibility and mining, respectively, but we do not discuss them here, given their comparatively small size.

Both topic modelling and the citation analysis identify discourses on DMDU, sea-level rise, and climate change adaptation and resilience. The topic modelling identified separate topics on land use and climate mitigation, integrated water management, and flood risk, but none of them have a corresponding community in the citation analysis. This suggests that from a citation point of view, these topics are subsumed by the other bodies of literature. A possible explanation for this is that these topics are discussed within, e.g., the DMDU literature. It might also reflect a bias in the corpus, which only contains papers citing one of three foundational pathway papers. The citation analysis revealed small communities on social corporate responsibility and mining. Neither of these show up in the topic modelling, possibly because the number of articles discussing these themes is too small to be revealed in the 8 chosen topics.

3.2. For what purpose and where is an adaptive pathways approach used?

3.2.1. Purposes

The main reason for choosing an adaptive pathways approach to adaptation is that it offers a structured way to achieve flexible and adaptive decision making to manage uncertainties, and identify near-term low-regret options, path-dependencies and potential maladaptation, with climate change as one of the main uncertainties (Barnett et al., 2014; Hanger-Kopp et al., 2022; Magnan et al., 2020; Magnan and Duvat, 2020; Werners et al., 2021a). In addition, (changing) values (Butler et al., 2016a,b; Colloff et al., 2021; Wise et al., 2014) or (dis)agreements on goals (e.g. Bosomworth et al., 2015; Coulter, 2019; Henrique and Tschakert, 2021) are put forward as important to consider in pathways exploration, which is also a source of deep uncertainty (Lempert, 2013).

While the majority of papers is about adaptive pathways for the future (87 %), a considerable body of literature looks at the past to understand historical development (13 %), what drives adaptation (Cao et al., 2021; Fazey et al., 2016; Gomes, 2022; Nguyen et al., 2019; Yanda et al., 2023) to gain insights into how to navigate the future as well as how history influences the future solution space (Bardsley et al., 2018; Burnham and Ma, 2018; Duvat et al., 2020; Garrick and Hall, 2014; Magnan and Duvat, 2020; Zandvoort et al., 2017). These papers typically discuss lock-in, path-dependency and institutional changes (Burnham and Ma, 2018; Joo and Sinha, 2023; Sadoff et al., 2015; Seebauer et al., 2023).

3.2.2. Applications

Based on the literature assessment, we find that the adaptive pathways approaches have been applied in various case studies and further developed in various policy domains with water and agriculture as dominant applications (Table 1). This is not surprising, as the approach originates from the water domain, and both water and agriculture are topics that dominate the adaptation literature (Berrang-Ford et al., 2021). Other domain applications are urban drainage and planning, transport, natural resources management, sustainable development and climate mitigation, which reflects the historical use of the pathways concept (see introduction).

Most case study papers are in the global regions of Europe, Asia,

Table 1
Policy domains of papers with a case study, method development or both.

Policy domains	Number	Example studies
Agriculture and Forestry	36	Colloff et al., 2016; Cradock-Henry et al., 2020; Petr et al., 2015; Vizinho et al., 2021; Yanda et al., 2023
Climate mitigation	10	Cuppen et al., 2021; Mathy et al., 2016; Michas et al., 2020; Roelich and Giesekam, 2019
Ecosystem, natural resources management	7	Bosomworth et al., 2015, 2017; Jacobs et al., 2018; Magness et al., 2022; Serrao-Neumann et al., 2015
Sustainable development	7	Butler et al., 2016c; David Tàbara et al., 2018; Mendizabal et al., 2021; Totin et al., 2021
Transport	6	Asian Development Bank, 2022; Hadjidemetriou et al., 2022; Soria-Lara and Banister, 2017
Urban drainage, spatial planning and heat risk	26	Buurman and Babovic, 2016; Carstens et al., 2019; Grace and Thompson, 2020; Kingsborough et al., 2017; Metro Los Angeles, 2019
Coastal management	50	Barnett et al., 2014; Glavovic et al., 2022; Hall et al., 2019; Kool et al 2020; Ramm et al., 2018; Ranger et al., 2013; Ryan et al., 2022; Thames Coromandel District Council, 2023; van Alphen et al., 2022
Water resources management	19	Bednar-Friedl et al., 2022; Gilroy and Jeuken, 2018; Gold et al., 2022; Kingsborough et al., 2016; Trindade et al., 2019; Zeff et al., 2016
Fluvial and other pluvial flooding	15	Bednar-Friedl et al., 2022; Bloemen et al., 2019; Haasnoot, 2013b; Lawrence et al., 2019; Muccione et al., 2024
Water general or multiple drivers (21)	20	Gomes, 2022; Haasnoot et al., 2018; Mach et al., 2022; Trindade et al., 2020; Zevenbergen et al., 2016

Australasia and North America, with countries like Australia, New Zealand, the Netherlands, the United Kingdom, the USA, and Indonesia described in most papers (6 to 22 papers; Fig. 3). Applications in the global south and low-income countries are limited, in particular in Africa and South America. Adaptive pathways studies mostly address physical climate drivers to explore pathways against, such as sea-level rise, rainfall, river flows and temperature change (63 %). Several papers address multiple physical drivers, and some also address socio-economic changes such as population change, perspective change and development or combinations thereof (21 %). Pathways are typically developed to support local adaptation, while some studies have assessed literature to design generic adaptation pathways for different archetypes (Glavovic et al., 2022; Haasnoot et al., 2019b; Bednar-Friedl et al., 2022; Muccione et al., 2024).

3.2.3. *From theory to practice*

We found multiple lines of evidence that an adaptive pathways approach has moved from theory to practice. First, we find that an adaptive pathways approach has been incorporated and tailored in guidance documents to support local applications and specific policy domains (Table 2). Second, we know from our network that various regions have picked up the approach (e.g. indicated by practitioners working on or having an adaptive pathways plan). Regions where the adaptive pathways approach has been or is being applied, include, for instance, New Zealand (Dunedin City Council, 2022; Lawrence et al., 2018; Lawrence and Haasnoot, 2017; Stroombergen and Lawrence, 2022; Thames Coromandel District Council, 2023), the Netherlands (Bloemen et al., 2019; Delta Programme, 2015; van Alphen et al., 2022), Australia (CoastAdapt, 2017; Lin et al., 2017), USA (Jayantha et al., 2020), Bangladesh (General Economics Division, 2018; Government of the People's Republic of Bangladesh, 2022) and UK (Ferranti et al., 2021; Ranger et al., 2013; Thames Water, 2019). Third, the scientific literature contains several case studies. From the total papers assessed, 70 % (167 of 238) had a case study, of which 42 % used a mix of theoretical and real-world practice studies for method development. From the total studies with a case, 41 % (68 of 167) had stakeholder involvement, which may inform adaptation decision making in the real world, but this does not mean that the study led to an adaptive plan or can be classified as a practice case study based on empirical evidence. A recent study assessing the status of coastal adaptation in practice found some evidence of pathways-like studies mostly in high-income regions (8 out of 61 regions assessed), but the global adaptation gap compared to the full potential of pathways-like approach was assessed at 62 % (Magnan et al., 2023).

Guidance is found in various policy domains and locations (Table 2). In some, pathways are introduced as a step in a broader policy process (e.g. Baker et al. (2019); State of California (2018)). Guidance plays a key role in introducing the approach to a new domain (e.g. for the mining sector by the International Council on Mining and Metals (Haworth et al., 2019). In many cases the guidance is tailored to the decision context and/or focuses on a specific element of the adaptive pathways' development process. For example, the CRIDA and ADB guidance use an uncertainty-impact matrix for decision makers to determine whether the problem at hand is suitable for an adaptive pathways approach (Mendoza et al., 2018; Warren et al., 2021). Both the UK adaptation (BSI, 2021) and ADB guidance (Warren et al., 2021) adopted the idea of a staged approach to pathways design following three levels of analysis of increasing detail and complexity; a concept

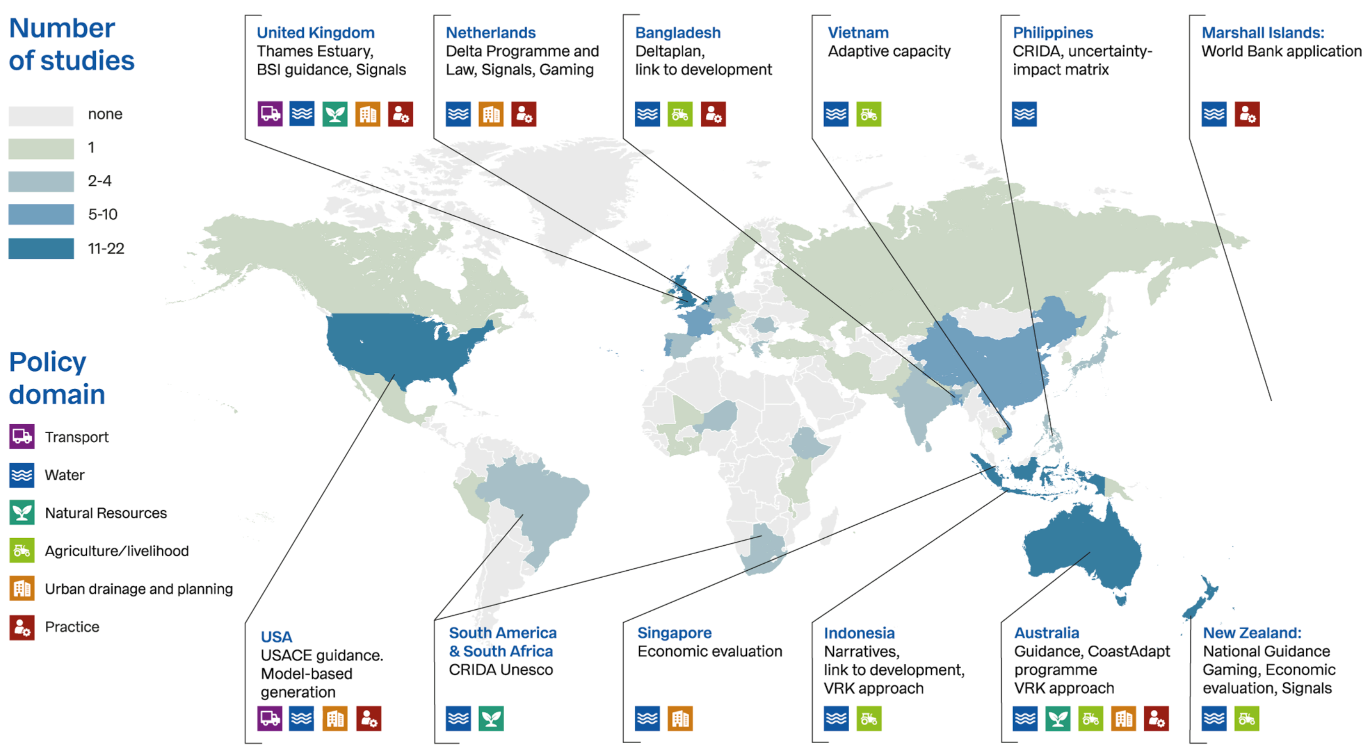

Fig. 3. Countries with pathways case studies, highlighting some regions and their characteristics. Example studies include USA: (Aerts et al., 2018; Mendoza et al., 2018; Tariq et al., 2017; Zandvoort et al., 2019; Zeff et al., 2016); South America & South Africa: CRIDA applications (Jordhus-Lier et al., 2019); UK: (Babovic and Mijic, 2019; Hall et al., 2019; Kingsborough et al., 2016; Ranger et al., 2013; Townend et al., 2021); The Netherlands: (Bloemen et al., 2017; Bloemen et al., 2019; Haasnoot, 2013b; Hermans et al., 2017; van Alphen et al., 2022; van Veelen et al., 2015); Bangladesh: (Gomes, 2022; Government of the People's Republic of Bangladesh, 2022; Hossain et al., 2018; Roy et al., 2021); Philippines: (Gilroy and Jeuken, 2018); Viet Nam (Hoang et al., 2023; Nguyen et al., 2019; Radhakrishnan et al., 2018; Scussolini et al., 2017); Marshall Islands: (The World Bank, 2021); Indonesia: (Butler et al., 2016a, 2016b; Butler et al., 2014; Jeuken et al., 2014; Wise et al., 2016); Australia: (Bosomworth et al., 2015; CoastAdapt, 2014, 2017; Colloff et al., 2016; Lin et al., 2017; Ramm et al., 2018); New Zealand: (Allison et al 2023; Bell et al., 2017; Kool et al., 2020; Lawrence and Haasnoot, 2017; Stephens et al., 2017; Stroombergen and Lawrence, 2022); Singapore: (Buurman and Babovic, 2016; Garrick and Hall, 2014; Manocha and Babovic, 2017).

Table 2
Guidance that incorporates an adaptive pathways approach to support adaptation decision making, their decision domain, location and key characteristics.

Where	Key characteristics	Reference
Generic adaptation		
UK	Includes basic steps for a pathways plan. Describes levels of analysis to pathways design from qualitative to quantitative. Explicitly mentions to use not only likely scenarios. Examples: Thames Estuary, London water resources investment, Eyre Peninsula.	BSI (2021)
UK	An adaptive pathways approach is listed as one of the main suggested decision-making tools, specifically their application with evolutionary algorithms.	Baker et al. (2019)
Australia	Explains stepwise approach to pathways in participatory setting, which can be extended with quantitative analysis. Example of Eyre Peninsula, port, fire management.	Siebentritt and Stafford Smith, 2016
Global	Aimed at World Bank projects to make them more climate resilient through testing their vulnerability and robustness. Adaptive pathways approaches are mentioned as a tool to manage risk.	Ray et al. (2015)
Water – general		
The Netherlands	Integrates adaptation pathways and planned adaptation into 'adaptive delta management'. Specific attention to the monitoring process.	Delta Programme, 2015 van Rhee (2012)
Global, UNESCO	Contains stepwise guidance using a risk-based approach. Provides a matrix to assess whether an adaptive pathways approach is suitable for a specific issue/plan/project.	Mendoza et al. (2018) https://en.unesco.org/crida
Global,Water Partnership & UNESCO	A textbook to integrated water resources management, aimed at practitioners and students. Incorporated pathways analysis in their policy analysis. Distinguishes different planning approaches, with pathways as an approach to deal with the long –term and uncertain conditions.	Nauta et al. (2016); van Beek et al. (2022)
Asian Develop- ment Bank	Guidance targeted at ADB project officers and Developing Member Countries (DMC) partners who are faced with strategic IFRM planning questions. Based on the DAPP approach and complemented with an uncertainty and impact matrix (similar to CRIDA guidance) to assess the appropriateness of pathways analysis. Describes levels of analysis and hypothetical coastal case.	Warren et al. (2021); Warren et al. (2023) https://development.asia/explainer/5-step-rapid-approach-climate-resilient-investment
Coastal management		
Australia Queensland	When identifying potential adaptation options it recommends considering interim measures evolving over time (pathways) Holding a stakeholder workshop during the option identification process is recommended as a minimum requirement.	Local Government Ass. of Queensland and Department of Environment and Heritage Protection (2016)
Australia	Guidance for practitioners on assessment and implementation of coastal adaptation. Examples of Lake Entrance, The Eyre Peninsula (Australia), Thames (UK). Guidance for water infrastructure decision making to integrate climate change into long- term planning	CoastAdapt (2017)
Denmark	Adjusts DAPP to Danish conditions, builds on experiences of Danish Coastal Authority with EU InterReg NSR project FRAMES. Examples: Assens & Vejle	Jumppane Andersen et al. (2020)
New Zealand	DAPP is central to guidance on coastal planning to consider progressive and ongoing risks from erosion and sea-level rise, that avoids path dependency, lock-in and maladaptation. Includes case studies that show the contribution of local and Indigenous knowledge and in engagement processes. Includes how early warning signals, triggers and thresholds for monitoring changing conditions to enable pre-emptive adaptation can be designed and used (Thames Coromandel District Council; Auckland Council).	Bell et al. (2017); Lawrence et al. (2018); Lawrence and Allison (2024)
Pacific region	Guidelines to encourage the deployment of dynamic adaptive pathways for infrastructure. Specific attention to mobilizing communities and rethinking futures. Case study Marshall island	PRIF, 2021
USA	Instructional and procedural guidance for assessment and adaptation to SLR impacts on USACE projects. Introduces three levels of complexity to identify tools for impact analysis. Hypothetical example for coastal flood and wetland restoration.	USACE (2019)
USA	Pathways considered as a last step and developed only if deemed necessary	State of California (2018)
Natural resources management		
Australia Southern Slopes	Includes generic steps to pathways planning and describes why and how it can be used for NRM. An iterative process for adaptive planning, includes a final step for Monitoring, Evaluation, Improvement & Learning	Bosomworth et al. (2015); Serrao-Neumann et al. (2015)
Australia	Proposes use of an adaptive pathways approach to flexible and adaptive planning, mentions trigger points to consider switching actions, and lead times. Example of Eyre Peninsula.	Rissik et al. (2014)
Other (agriculture, infrastructure, mining)		
UK	Contains a generic framework for infrastructure (e.g. reservoirs, tunnels, roads, bridges, underground pipes). It includes a specific step for identifying interdependencies between measures. Examples from Thames Estuary, Thames Water Resource Management Plan (UK), New York Metropolitan Risk (USA), Dutch Delta Programme, Coastal Adaptation Pathways Programme (Australia).	Quinn et al. (2018); Ferranti et al. (2021)
Canada – British Columbia	Developed for communities or local governments with the aim to provide a non-technical, user-friendly overview to start developing adaptation pathways. Hypothetical example for sustainable local food production under low river flows.	Coulter (2019)
Global	Contains a stepwise process for identifying climate risks and measures including a step on developing adaptation pathways. Hypothetical example on water scarcity and consequences for a local community.	Haworth et al. (2019)

which emerged from applications in practice (Haasnoot et al., 2019a). A variant of the staged approach is reflected in the New Zealand coastal guidance to use a high-level DAPP for scoping areas for high risk and then to develop detailed pathways for new developments (Bell et al., 2017; Lawrence and Allison, 2024). Several guidance discuss the use of models (Baker et al., 2019; Mendoza et al., 2018; Ray et al., 2015) and many present processes for stakeholder engagement (Bell et al., 2017; Local Government Ass. of Queensland and Department of Environment and Heritage Protection, 2016; Siebentritt and Stafford Smith, 2016). Werners et al., 2021a introduce a learning framework to provide guidance for the systematic reflection on the use (and related framing) of adaptive pathways approaches. Guidance so far has not yet addressed in depth advances in pathways design, including transformative adaptation, maladaptation, or implementation of adaptive plans (Magnan et al., 2020).

3.3. How are adaptive pathways assessments done?

3.3.1. Pathways design

Pathways can be designed quantitatively using models and/or qualitatively based on expert/stakeholder assessment. Models are used to quantify the undesirable conditions and their timing when new or additional adaptation options are required to meet objectives using a set of scenarios (e.g. Haasnoot et al., 2019a; Kwakkel et al., 2015). What is undesirable is derived from objectives set in law or policy studies, or through stakeholder engagement (e.g. climate risk becomes unacceptable). By using information on the effectiveness of adaptation options and combinations as well as their path-dependency (e.g. actions that are prerequisite or exclude each other), pathways are systematically constructed (e.g. Haasnoot et al., 2019a; Muccione et al. 2024). Criteria used to start sequencing include: effectiveness (e.g. reduce risk) and co-benefits (e.g. equity, nature, livelihood), influence on other measures (create barriers or facilitate), uncertainty in adaptation needs (e.g. some measures are only needed in the long-term and/or under limited futures), implementation time, feasibility and opportunities of actions (e.g. available financing, law, innovation) (Abel et al., 2011; Barnett et al., 2014; Haasnoot et al., 2019a; Warren et al., 2021, 2023).

Tools, such as the pathways generator tool (https://pathways.deltares.nl), are available and have been used to assist in the design of pathways with experts and stakeholders complemented with literature and/or model assessment (e.g. Hossain et al., 2018; Lawrence et al., 2019a; Radhakrishnan et al., 2018). Models can generate pathways based on trigger conditions that initiate new adaptation options (e.g. Gold et al., 2022; Hamarat et al., 2014; Kwakkel et al., 2016; Toimil et al., 2021).

In a participatory approach, stakeholders are involved in developing a vision, identifying objectives, threshold conditions, adaptation options and pathways. For example, Campos et al. (2016) and Vizinho et al. (2021) extended the DAPP approach through scenario workshops and thereby reached socio-political legitimacy and trust in the results. Roy et al. (2021) designed pathways through interviews and participatory workshops for livelihood resilience. Carstens et al. (2019) developed what they call a DAPP-light approach through stakeholder workshops that aimed to 1) agree on the problem, criteria for success, undesired events; 2) identify vulnerabilities and possible actions; 3) develop and evaluate possible pathways and discuss implementation and monitoring. Socialising stakeholders with the approach through serious gaming, has proven to prime participants and thus help start the design of pathways (Lawrence and Haasnoot, 2017).

Pathways design typically follows a staged and iterative approach wherein pathways are explored, screened, and further elaborated and selected. This follows different levels of analysis, from a qualitative assessment based on narratives and literature, to a more comprehensive model-based assessment, all with stakeholder involvement (Section 3.1).

Both forecasting and backcasting has been used to design pathways (Prasad et al., 2023). Most studies assessed follow a forecasting approach based on the notion of adaptation thresholds. Some suggest that this results in incremental pathways (Bosomworth et al., 2017). However, identifying limits to current and future adaptation strategies can illuminate the need for transformative adaptation, if the system is sufficiently stressed against changing conditions (e.g. low-likelihood or longer time horizon; Haasnoot et al., 2020; van Alphen et al., 2022). A backcasting approach to pathways starts with future end-states and explores alternative pathways (Bergeret and Lavorel, 2022; Mendizabal et al., 2021; Soria-Lara and Banister, 2017) and pivotal decisions to get there (van Alphen et al., 2022).

3.3.2. Pathways visualisation

Visually representing adaptation with steps over time helps to link short-term actions with the long-term and overcome barriers and decision paralysis (Bloemen et al., 2019; Haasnoot et al., 2019a; Kingsborough et al., 2016; Warren et al., 2021). About half of the case studies visualise pathways. Analysing the pathways figures, we distinguish five visualisation types: metro-map, decision tree, bar-plot, timeline, and solution space (Fig. 4). The metro-map is used most frequently (61 %), while the other types comprise 6–11 % each.

The metro-map visualisation, inspired by subway maps, presents options, endpoints, and transfer points between pathways thereby showing flexibility, lock-in and maladaptation. Metro-maps can use adaptation thresholds when new measures are needed (panel A; Kwadijk et al. 2010; Werners et al., 2013), indicate reasons to adapt further (panel B; (Bednar-Friedl et al., 2022; van Alphen et al., 2022), or present short, mid to long-term options (panel C; Bloemen et al., 2017; Delta Programme, 2015). The latter two are typically used when limited quantitative information is available. Spatial pathways can be used to show how decisions taken in one area can be connected to others (Kool et al., 2020, 2023). To help address complexity, a nested pathways approach can be taken, showing high-level pathways in addition to a detailed map (e.g. Haasnoot et al., 2021). Some indicate the frequency of when a specific measure is triggered based on an exploratory modelling analysis (Gold et al., 2022; Zeff et al., 2016), and some have indicated pathways for different actors (Delta Programme, 2015). A decision tree illustrates how decision sequences can branch out, as is done e.g. in combination with a real options analysis (Buurman and Babovic, 2016; Radhakrishnan et al., 2018). Some are a decision tree resulting from answering different questions (Costa et al., 2021; Doherty et al., 2017). Bar-plots show a sequence of measures based on their functional lifetime (similar to adaptation thresholds) (Cao et al., 2020). They enable many pathways to be shown, and when stacked, they look like a Mondriaan painting (Trindade et al., 2019, 2020). Some have used a widening or collared bar to indicate the scale of the measure (Hall et al., 2019; Kingsborough et al., 2016) or a shrinking bar to indicate reducing performance (Colloff et al., 2016; Magnan and Duvat, 2020). Timelines are used to describe a comprehensive single pathway in the past or future with climate and socio-economic conditions that trigger or enable measures to be implemented (Barnett et al., 2014; Câmpeanu and Fazey, 2014; Rosenzweig and Solecki, 2014; Sadoff et al., 2015). Some studies use illustrations or spatial designs (Esteban et al., 2020; Jeuken et al., 2014; Zhang et al., 2023). A solution space graph is used for pathways metaphors showing the adaptation and maladaptive space (Colloff et al., 2017; Wise et al., 2014) and for showing how changing conditions and actions can shape this space (Haasnoot et al., 2020, 2021).

3.3.3. Pathways evaluation

Similar to the pathways design, the evaluation of alternative pathways to support decision making can be undertaken qualitatively, relying on expert judgement, using scorecards, or through various forms of stakeholder engagement, and quantitatively using exploratory modelling to simulate the performance for a wide range of futures. We found 36 papers using quantitative methods, including: multicriteria analysis (13 papers, e.g. Townend et al., 2021; Tsubouchi et al., 2021; Zandvoort et al., 2019), cost-benefit analysis (18 papers; Aerts et al.,

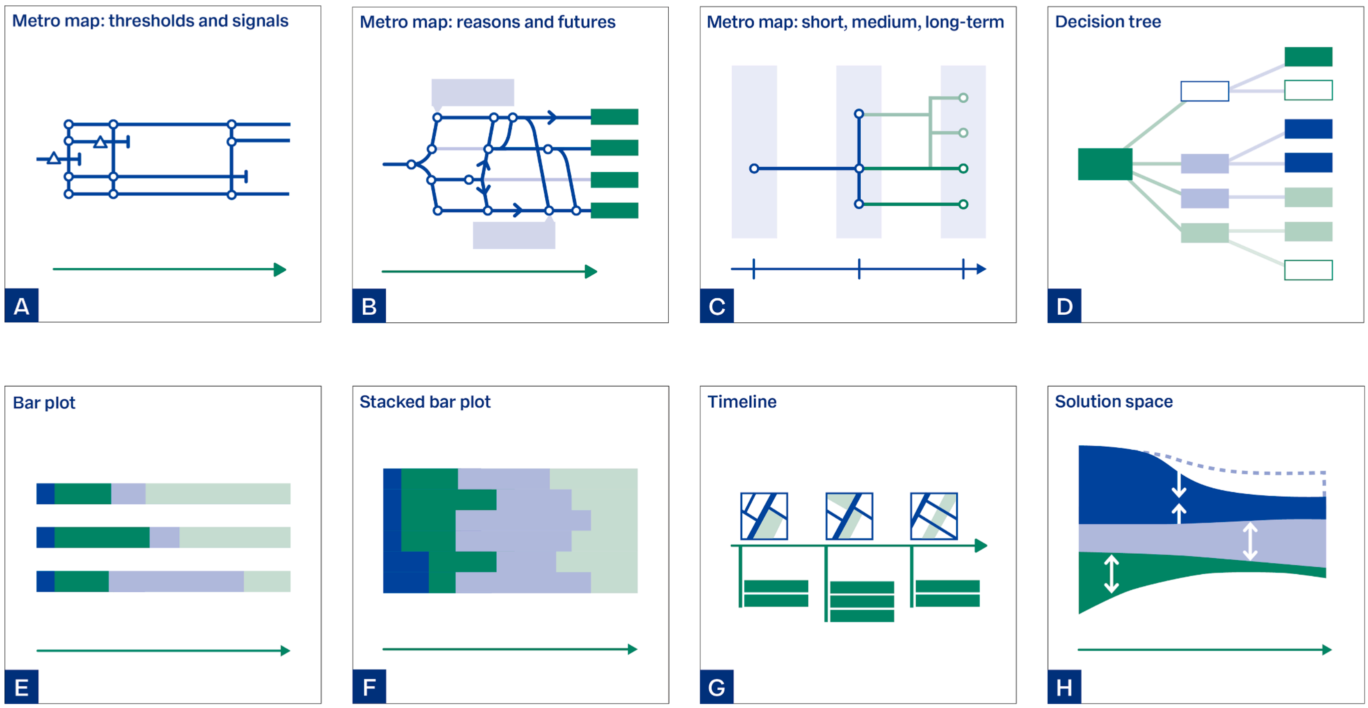

Fig. 4. Visualisation styles of adaptation pathways. Metro map: shows options, lock-ins and potential transfers to other options and pathways, similar to a metro/subway route map. Different types exist presenting: a) adaptation tipping points or thresholds (vertical lines) when the action no longer meets objectives and further adaptations are required (panel A); b) pivotal decisions with a description of reasons to adapt further (grey boxes) and future end-states (green boxes at the end of the pathways) (panel B); or c) short, medium, long-term adaptation portfolios (panel C). Decision tree: shows branches with options and thus the available options left after a decision (panel D). A (stacked) bar-plot shows the functional lifetime of adaptation measure, similar to a Gantt chart and adaptation tipping point (panels E and F). Shifts between pathways are implicit. Timeline: show measures in relation to events (panel G). Solution space (panel H): shows a space for actions, typically used as a metaphor to illustrate the adaptation envelope and how this is enabled or constrained, or how adaptation moves to the maladaptive space (dashed area). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2018; das Neves et al., 2023; de Ruig et al., 2019; Shan et al., 2022), and real options analysis (5 papers: Buurman and Babovic, 2016; Lawrence et al., 2019b; Manocha and Babovic, 2018; Ryan et al., 2022). The latter complements cost-benefit analysis by highlighting the value of flexibility. However, others have argued that the complement of this value of flexibility, is the costs of lock-in (Kwakkel, 2020). To address this Haasnoot et al. (2019c) propose transfer costs as a way of making transparent the financial costs of lock-ins.

While most studies use some form of multi-criteria decision analysis to aggregate the performance across objectives into a single measure of fitness, there is also a group of quantitative evaluations that design through iterative stress-testing, through many-objective optimization with subsequent evaluation over a wider set of scenarios. This group is rooted in (many-objective) robust decision making (Groves and Lempert, 2007; Kasprzyk et al., 2013). To summarize the results, attention is given to the robustness, measured using regret or satisficing robustness metrics (McPhail et al., 2018). These techniques also pay particular attention to trade-offs across different objectives. Qualitative and quantitative approaches can also be combined. For example, Cuppen et al. (2021) use a participatory sensemaking approach to interpret quantitative results. While some studies have looked at the single best pathway (e.g. Manocha and Babovic, 2017, 2018; Zhang et al., 2023), this moves away from the central purpose of using pathways to manage uncertainties by stress testing across a range of futures.

The performance can be presented in tables (e.g. Haasnoot et al., 2019a; Stroombergen and Lawrence, 2022), time-series (e.g. de Ruig et al., 2019; Toimil et al., 2021), or as parallel coordinate plots (e.g. Trindade et al., 2020; Zeff et al., 2016). Adaptive planning requires new performance indicators that focus on delivering long-term benefits rather than short-term fixes (Malekpour and Newig, 2020). Disaggregation of impacts over time, space and actors helps to address equity in the pathways evaluation (Jafino et al., 2021). Considering multiple values is used to find socially robust pathways that account for value change (Haasnoot et al., 2012; Offermans, 2012). Despite its importance for evaluation, not all studies present the performance.

3.3.4. *Monitoring for signals*

While many studies acknowledge the need to monitor, the development of monitoring plans to support appropriate and timely adaptation, is still developing in practice and in science. In our assessment, we find several studies that have identified indicators to monitor (18 papers, e.g. (Campos et al., 2016; Ke et al., 2016; Magness et al., 2022) and some that have also defined values that trigger follow-up actions, typically used to generate pathways with models (13 papers; (Allison et al., 2023; Buurman and Babovic, 2016; de Ruig et al., 2019; Grace and Thompson, 2020; Little and Lin, 2017; Toimil et al., 2021). A few studies have tested climate related signposts (indicator values for signals) for adaptation (e.g. Haasnoot et al., 2015, 2018; Raso et al., 2019a, 2019b; Stephens et al., 2018). Hamlington et al. (2023) elaborate on the use of satellite information for signals. The importance of institutional embedding of monitoring and learning is discussed by Hermans et al. (2017), Butler et al. (2016a), Bell et al. (2017) and Lawrence et al. (2018). Hinkel et al. (2019) and Völz and Hinkel (2023) introduce the idea of learning scenarios, providing probabilities of a climate variable at a future moment in time, to evaluate how learning can be used for adaptation decision making.

Monitoring for signals is done in practice, for example, in the Thames Estuary plan (Environment Agency, 2012), the Dutch Delta Programme (Haasnoot et al., 2018), and New York (Rosenzweig and Solecki, 2014; Blake et al., 2019). These practices use indicators for climate change, socio-economic developments (e.g. changes in population or land/water use change), impacts, vulnerability, and changes in values. They also planned to have an ongoing assessment of changes and planned to evaluate regularly (e.g. ongoing and every 6 six years in New York and in the Netherlands).

3.3.5. Implementation and institutional arrangements

Institutional embedding of adaptive pathways planning, and derived plans is required for implementation. Lin et al. (2017) identified the lack of clarity on responsibilities and institutional, legal and financial implications as one of the major challenges in implementing the results from using a pathways approach. Similarly, Tariq et al. (2017) discuss that while US law allows agencies to develop adaptive plans for water management, they have been rejected in court because of lack of specificity on how they will achieve their regulatory mandates. Others have addressed this by identifying barriers for pathways implementation (Roy et al., 2021) or by complementing pathways with institutional settings and socio-economic scenarios that would support pathways implementation (van der Brugge and Roosjen, 2015). Only a few papers address institutional arrangements and enabling conditions related to implementation (Table 3; Sparkes et al. (2023)), but some guidance addresses the institutional context and the inclusion of stakeholder and agency values (e.g. Table 2). To date, few pathways once developed have been fully implemented globally due to 1) difficulty in integrating them into the largely static planning instruments used; 2) reluctance of decision makers to create uncertain operating conditions for developments; 3) pressures from development interests to reap financial gains from developments in the short-term, combined with short political cycles of consenting agencies (Biesbroek et al., 2013; Schneider et al., 2020).

From the literature and our experience, we identify the following components to facilitate the implementation of an adaptive pathways planning approach: knowledge and capacity development (Alaerts and Kaspersma, 2022; Butler et al., 2016b; Frantzeskaki et al., 2019); long-term political commitment and dedicated governance through long-term funding, law and regulations (Bloemen et al., 2019; Frohlich et al., 2019; Garrick and Hall, 2014; Lin et al., 2017; Magness et al., 2022; Malekpour and Newig, 2020; Pentz and Klenk, 2020) creation of a culture of learning and facilitation of learning through monitoring and evaluations (Butler et al., 2016; Hermans et al., 2017; McNicol, 2021; Pot et al., 2023); clarity of organisational accountabilities (Hermans et al., 2017; Lin et al., 2017); and leadership and support for emergent leaders and brokers (Butler et al., 2016b, 2022; Lawrence and Haasnoot, 2017; Totin et al., 2021). For example, in the Netherlands, the Delta Programme received long-term funding, is supported by law, and plans to evaluate the progress of the adaptive plan every six years (Bloemen et al., 2019).

3.3.6. Innovations and extensions

Our review reveals that an adaptive pathways planning approach, like DAPP, is increasingly being extended, complemented with or incorporated in other methods and tools to tailor the approach and address limitations (Table 3, previous sections), which is also noted by Werners et al., 2021a. For example, participatory scenario and pathways development analysis (Bhave et al., 2022; Bosomworth et al., 2015; Campos et al., 2016; Vizinho et al., 2021), real options analysis (Buurman and Babovic, 2016; Lawrence et al., 2019b), and exploratory modelling and stress-testing tools (Kwakkel et al., 2015; Mendoza et al., 2018; Zeff et al., 2016) have been used alongside adaptation pathways. Determining thresholds that require further adaptation is one of the challenges mentioned (Bloemen et al., 2017; Kingsborough et al., 2017; Vizinho et al., 2021) because of a lack of institutional embedding, or disagreement or difficulty in defining precise goals such as risk acceptance. To address these challenges, it can help to start with sequencing measures and keeping the thresholds ambiguous (e.g. Bloemen et al. (2017); Fig. 4), identifying triggers for further adaptation with stakeholders (e.g. Barnett et al. (2014) or assessing the sensitivity of different values when evaluating pathways. Several papers discuss how values and cultures can be embedded into pathways exploration through participatory analysis (Bosomworth et al., 2015; Butler, et al., 2016b; Prober et al., 2017; Sparkes et al., 2023). Some guidance also sets out how to do this using participatory processes to identify values and cultural traditions that can be incorporated into pathways (Bell et al., 2017). Pathways which currently often only include physical measures can be complemented with enabling conditions such as institutional measures and socio-cultural conditions (Haasnoot et al., 2021; Lawrence et al., 2021; van der Brugge and Roosjen, 2015).

Most of the adaptive pathways studies are oriented at performance and consider multiple actors, but there are few oriented at transformation (clusters distinguished by Werners et al. (2021a)), which is also found for adaptation in general (Berrang-Ford et al., 2021). Transformative adaptation, however, is emerging in the literature (Triyanti et al., 2020). Pathways have formed part of framing intentional transformative adaptation (Colloff et al., 2021) and when governance enablers are absent (Abel et al., 2016). Fook (2017) discusses how adaptation is an opportunity to trigger transformational adaptation, and Termeer et al. (2017) argue that a series of small wins can result in transformative adaptation. Haasnoot et al. (2021) show how DAPP can be used to provide insights into how inevitable transformation can be progressively staged via planned managed retreat in coastal settings where sea-level rise is advancing.

Climate Resilient Development Pathways (CRDP), integrating climate adaptation, mitigation, and sustainable development for all, have also been gaining traction, although this remains a very new field (Werners et al., 2021b). Singh and Chudasama (2021) use fuzzy cognitive map-based simulations to identify key enabling conditions for CRDP. Taylor et al. (2023) review the operationalisation of CRDP in the Global South and conclude that successful and just CRDPs require both technical and relational capacities and a new CRDP-specific methodology and skill set. At the same time, they find that many CRDP operationalisations to date mostly result in what look like adaptation pathways, but without exploration of co-benefits and synergies between mitigation-adaptation-sustainable development.

Table 3
Method developments.

Where did method development focus on	Number of papers	Percentage
Scoping uncertainties, stakeholders, objectives, culture	14	11 %
Vulnerability and risk assessment	12	9 %
Options identifications	5	4 %
Pathways design (e.g. generation, institutional issues)	33	25 %
Evaluation of Pathways	22	17 %
Monitoring (e.g. what to monitor)	13	10 %
Implementation (e.g. institutional issues, governance)	12	9 %
Multiple	22	17 %

3.4. How has the use of adaptive pathways approaches contributed to decision making?

3.4.1. Built confidence and trust in decision makers

A pathways approach to adaptation has given decision makers greater confidence that there are robust policy choices that can be relied upon even though the future is uncertain. This is demonstrated in the wide range of applications in real-life decision processes worldwide (Table 2; Fig. 3). When used with participatory processes (Campos et al., 2016; Carstens et al., 2019; Vizinho et al., 2021; Werners et al., 2021a), which draw from community values (Ryan et al., 2022), the approach has helped to build trust in decision makers and the decision-making processes where there are conflicting interests amongst decision agents both public and private, who often have varying degrees of power and access to decision rights (Boston, 2017).

3.4.2. Opening up space for understanding of risks and solutions

The approach has enabled a greater understanding of the fundamentals of managing risk and uncertainty and the solution space. Setting up inclusive and timely governance (Ryan et al., 2022) has enabled engagement between communities and decision makers, which has leveraged a greater understanding of the problems being addressed (Carstens et al., 2019; van Alphen et al., 2022). This has enabled implementation constraints to be considered early in the process, resulting in more realistic adaptation options, with the added benefit of the shrinking space for adaptation to be identified and acted upon. A focus on the lifetime of decisions, the potential for lock-in, and the lead time required to implement decisions, has drawn attention to the legacy effect of permanence of adaptation options that reduces options going forward and increases the potential for maladaptation. Using the approach helps spot the limits of different options, widens the solution space, and includes consideration of surprises and the 'implausible' which cannot be ruled out (Haasnoot et al., 2019c; Lawrence and Haasnoot, 2017; Ryan et al., 2022).

For example, when developing storylines for the Delta Programme, the approach helped participants to identify key decisions and potential lock-ins (Haasnoot, 2013b). Participants became aware of their implicit preferences for riverbed widening and levee height when identifying options and path-dependencies. This helped them identify what actions should be taken immediately to realize targets in the near-term and what actions should be taken to keep some options open for the long-term. They concluded that the solution space was larger than they imagined and that not considering the larger solution space could result in a lock-in. Lin et al. (2017) concluded that if there is limited stakeholder engagement, the range of adaptive pathways may be too narrow, preventing the full potential of the adaptive pathways approach. This is about water management, but Magness et al. (2022) discuss the potential to open up the solution space for natural resources management more widely. In another example (Kool et al., 2020), participants in an exploratory DAPP developed a sequence of transformative actions over time when presented with the limitations of a gravity-fed stormwater system in a spatial retreat context, thus widening the range of options that could be considered and the timeframes available for them. If goals are transformative, sequencing of adaptation actions over time can reveal lock-in/lock-out and thus limits to the options. This opens up a discussion of the need for transformation.

3.4.3. Enhanced the need for anticipatory planning and widened decision makers horizons

DMDU approaches, in general, have begun to shift the dial from responding in the short-term towards anticipating and planning for the longer-term consequences, especially in coastal areas where change is ongoing and progressive (Haasnoot et al., 2021; Hinkel et al., 2019; Magnan et al., 2020; Stephens et al., 2017). This has involved wider use of scenarios, including high-impact-low-likelihood scenarios. The adaptive pathways planning approach has also highlighted for decision makers the cascading and compounding effects of climate-driven impacts across jurisdictional boundaries and highlighted institutional barriers in the law that create confusing mandates and impede the implementation of adaptive plans or reduce their effectiveness (Lawrence et al., 2021).

An example in the Eyre Peninsula, South Australia using pathways led to the understanding that investments can be staggered and that all actions are not needed in the short-term. This relieved decision makers' and community anxiety about adaptation (CoastAdapt, 2017; https://coastadapt.com.au/pathways-approach). However, an example from New Zealand for the Hutt River flood management (Lawrence et al., 2019a) showed that while decisions can be sequenced over time, citizens requested a transformational decision which involved managed retreat to make room for the river in the near-term, because the funding to implement the measures was available now and might not have been in the future. This was driven by fairness for those affected by acting now to reduce their ongoing uncertainty of response. Yet, another example (Carstens et al., 2019) showed that while the approach promoted vulnerability-based thinking among the end-users and generated new ideas on how to manage the uncertain long-term impacts of future sea-level rise, the increased understanding of uncertainties was used to justify static, rather than adaptive solutions. Perceived legal constraints, lack of experience of adaptive pathways, and unwillingness to prescribe actions that could prove difficult to enforce in the future dominated this decision. For a part of the city of Miami, an adaptive pathways analysis showed structural measures could buy time, but in the end transformative measures with land use changes would be needed (Jayantha et al., 2020). After Hurricane Sandy, the City of New York used flexible adaptation pathways to respond to climate change and the reduced risk appetite in the community, enabling near-term decisions to be made (Rosenzweig and Solecki, 2014).

Examples of practitioner and decision makers feedback on the use of an adaptive pathways planning approach highlight the value of the approach for understanding the problem space and for making robust decisions under changing physical and socio-economic conditions (see Appendix A.3).

4. Lessons and research agenda

4.1. Lessons learned on adaptive pathways analysis

1) **An adaptive pathways approach is useful but not always needed**

For decision analysis, an adaptive pathways approach like DAPP is particularly useful for new developments to avoid risk and the creation of further legacy effects that, under changing conditions, will become more costly to rectify. DAPP can also be used for existing locked-in developments by staging a transition away from accelerating risk locations in space. In general, the approach is useful for decisions or plans that a) have a long-term (multidecadal) lifespan or long societal impact, b) experience ongoing progression of impacts, c) are surrounded by uncertainties and can have a large impact, and d) have the potential for path-dependencies to emerge. However, exploring adaptive pathways is not always needed. If there is little uncertainty, or only one option, an adaptive pathways approach is unsuitable. When there is little uncertainty, and it is clear that a portfolio of options is needed, DAPP can be used to sequence options as has been done for the Philippines (van Aalst and Schasfoort, 2017). Before starting, screening can be done to assess whether a pathways decision analysis is fit-for-purpose and what level of analytical complexity is needed (as discussed by e.g. Mendoza et al., 2018; Stephens et al., 2017; Warren et al., 2021).

The structured stepwise decision analysis of adaptive pathways in combination with pathways visualisations has helped to get insight into the solutions space over time, generate new ideas for adaptation, identify path-dependency, barriers and opportunities, and link the long-term adaptation needs to near-term actions, in particular when done in a participatory setting and when supported with an assessment of the effectiveness of adaptation options. The visualisation is thereby a means to increase understanding and develop an adaptive plan and not a purpose in itself.

2) **An adaptive pathways analysis can be tailored to different decision contexts**

Our analysis shows that in the past decade, an adaptive pathways approach has been applied across the world and for different decision domains, in both science and practice, and in different decision contexts. How pathways are designed depends on local practices as also concluded by Zandvoort et al. (2017) and Werners et al. (2021a). Comprehensive applications in practice occur, however, in areas with multi-year programmes, resources available, and that were amongst the first adaptors of the approach (e.g., in the Netherlands, New Zealand, London, New York and Bangladesh). Applications in the global south and low-income countries are still limited. We hypothesize that experiences in long-term thinking, culture, capacities (e.g. Indigenous knowledge, data, technology, funding, people), or dealing with other near-term problems influence pathways use and application potential. For example, in New Zealand the Indigenous tangata whenua Māori have a long-term intergenerational worldview rooted in whakapapa (genealogical descent of all living things) and connectivity between people and the natural environment (Awatere et al., 2021; Roberts, 2013). This fits well with adaptive pathways thinking about long-term adaptive planning for global change. In western Europe, long-term thinking already exists for water management (e.g. the Delta works in the Netherlands and Thames Barrier in the UK were built for 100+ years). The scientific complexity and data and technological requirements are a challenge for adaptation decision making in general and in particular for adaptive pathways planning. A phased and participatory approach starting with pathways narratives and simple gaming has proven to be a way to trigger pathways-thinking (Lawrence and Haasnoot, 2017). For developing countries where poverty and short-term vulnerabilities dominate over long-term concerns, the approach may need to be tailored to be effective (Ranger and Garbett-Shiels, 2011). A strong link with sustainable development and inequality would therefore be essential (see for example the Bangladesh Delta plan, General Economics Division (2018)).

In Section 3.3 we highlight different components to facilitate implementation of an adaptive pathways planning approach based on the literature, such as dedicated governance, capacity, and culture of learning. In contrast, a fragmented governance structure with cross-dependencies between and lack of a culture of long-term thinking and trust in institutions could hamper good adaptation planning including adaptive pathways planning (Boston, 2016; Du et al., 2022; Juhola, 2016; Termeer et al., 2013).

While DAPP introduces a way to systematically explore pathways and stress-test them against a range of future conditions for their sensitivity to changing risk for developing an adaptive plan, it has been developed further and enriched with complementary methods and tools. DAPP can therefore be seen as an approach that can be combined with other DMDU methods and tools, as discussed by Kwakkel and Haasnoot (2019) and needs to be tailored to local decision context for successful implementation. The aforementioned importance of local decision context (inc. culture, knowledge, values and experience) is discussed by Butler et al. (2016a), Wise et al. (2014) and their approach of values, knowledge and rules helpfully grounds decision making in lived experience, as also recognized by Henrique and Tschakert (2021).

3) **Applying an adaptive pathways analysis takes time to think differently**

Technical and policy advisors to decision makers come from different professional traditions, which means the uptake of new thinking takes time (e.g. Carstens et al., 2019; Lawrence and Haasnoot, 2017; Totin et al., 2021). This highlights the need for guidance on introducing adaptive pathways thinking to contexts with urgent problems (e.g., post climate events, or when there is extreme poverty and inequality), or where the various parties to a decision have little experience with long-term thinking. In addition, exchanging experiences on adaptive pathways processes and the developed pathways themselves could further support this.

Complementary approaches that can help socialise the approach with practitioners and decision makers have been demonstrated in practice. Lawrence and Haasnoot (2017) showed how DAPP uptake was catalysed using a serious game with a knowledge broker, alongside reframing of the existing or new knowledge through cognitive learning, normative learning through convergence of group approaches, and through relational learning by experiencing the views of others that led to greater cooperation. Blackett et al. (2022) demonstrated how coproduction of a serious game with a Māori community in situ, supported the development of a culturally relevant DAPP for localised flood adaptation.

In a world where climate change impacts are increasingly felt and socio-economic developments are happening fast, an extended pathways approach that links adaptation to development, e.g. through operationalizing the CRDP, could help to accelerate decision making for the near-term, while taking time for long-term adaptation needs as also emphasized by the small-wins concept of Termeer et al. (2017). By breaking down the changing and uncertain components of the short- and long-term challenges, the adaptive pathways approach used with serious games to prime long-term thinking, can help motivate uptake of the approach and shift conventional ways of thinking (Haasnoot et al., 2021; Lawrence and Haasnoot, 2017).

4) **A staged approach from screening to detailed assessment can help to target the analysis and deal with complexity**

When new to the concept, an adaptive pathways approach can be perceived as complex (see point 3), and with an increasing number of measures and accounting for multiple uncertainties from different values, targets, actors and hazards, it becomes more difficult to see the forest for the trees. Simple participatory modelling and fast computing with stakeholders can break down barriers to complexity (Global Water Partnership, 2017) as have the use of serious games alongside DMDU methods (Lawrence and Haasnoot 2017). A staged approach that adds uncertainties and interactions, while also screening for promising pathways is a way of dealing with this complexity (e.g. Schlumberger et al., 2022). A staged approach also helps target a pathways analysis as one can start with a quick scan of pathways: leading into more detailed (model-based) pathways analyses, if and where necessary (Section 3.3). Starting with a scan of potential uncertainties, impacts, adaptation options and their sequencing into pathways, together with stakeholders and experts, can help set-up more detailed analyses which could involve more stakeholders and/or a model-based assessment. As a result, a pathways analysis can start with limited resources (e.g. time, capacity, and finance) and develop greater complexity where appropriate. This iterative approach is set out in some of the reviewed guidance documents.

5) **Adaptive pathways approaches can integrate changing and uncertain values and objectives**

The results of this literature review and practice examples show that different values and changing preferences over time can be accommodated by a) including diversity in values and objectives from the start in a participatory process; b) evaluating pathways for multiple indicators, areas, actors and time horizons; c) using signposts that signal changing values and objectives, and having the option to change pathways that meet changing objectives (see Section 3.2 and 3.3). DAPP does not aim to develop one deterministic pathway or only a single sequence, as this would remove the flexibility to change course, which is needed to deal with uncertainty, the main purpose of the DAPP approach.

6) **Considering the wider stakeholder and institutional context can enable pathways to be implemented**

The wide range of applications and guidance shows that adaptive pathways planning is being picked up in practice, although we found limited evidence of plan implementation. In general, adaptation options will be harder to implement if not designed with consideration of the land use planning and statutory and engagement contexts. The adaptive pathways approach can enable the barriers to implementation to become transparent, as potential lock-in is considered. Involvement of the decision makers throughout the process of pathways design, is equally as important as engaging with communities affected and critical to implementation.

To implement the outcomes of the exploration requires other drivers to be in place e.g. institutional arrangements, funding, and political will. Setting up governance arrangements to embed the adaptive pathways approach and its ongoing monitoring and using games to familiarise the actors with pathways in a 'safe space' for discussing conflicting objectives, assists in gaining buy-in to a wider range of adaptation options and pathways. Long-term funding of the adaptive pathways development, implementation, and its monitoring and review has been shown to be critical to addressing inertia at the implementation stage (section 3.3; (Anonymous, 2023)).

7) **Combining an adaptive pathways analysis with complementary methods and tools can enable transformative decision making**

To date, pathways development has often been incremental, while transformation may be needed. We have learned from experience that analysing both a 'push' (the need for transformation) and 'pull' (having an attractive transformational future) can support the development of transformational pathways. Stress-testing the system thoroughly – thus also for the long-term (beyond 2100) and also for low-likelihood high impact scenarios – and identifying adaptation thresholds for a wide range of adaptation options can inform the need for transformation. Participatory visioning and considering different goals can help to make an attractive future. A combination of a backcasting analysis and identification of multiple pathways widens enriches the decision/solution space and links an imaginable future to the near-term while accounting for uncertainties over the long-term. In such a study, an adaptive pathways analysis helps to break a complex adaptation challenge into manageable steps and to identify pivotal decisions, transfers between pathways, potential maladaptation as well as barriers, limits and opportunities. Understanding the feasibility of pathways through a comprehensive solution space assessment can identify actions (e.g. on regulations and institutions) to unlock pathways, enable pathways implementation and consider adaptation opportunities. This could inform transformative adaptation decision making and help operationalise CRDP.

4.2. Research agenda

With an adaptive pathways approach to adaptation now over a decade old, and with the increasing need for adaptation and the acknowledgement of uncertainties (IPCC, 2022), several research topics have emerged from our assessment that require specific attention:

With increasing climate change, **multiple and compound** hazards and **cascading** impacts will occur more often (IPCC 2022) but are underrepresented in pathways studies. Pathways are often developed from a social planner's perspective (one agent who does good for all), but in the real world, adaptation takes place in a **multi-actor** setting characterised by diverse values and perspectives. Pathways analysis could, therefore, advance by addressing interactions between hazards and adaptation actions of different actors and for different hazards. This research is emerging (Challinor et al., 2018; Schlumberger et al., 2022) and could be further developed and made more decision-relevant, for example, through interactive figures that allow for analysing results from different perspectives as done by Bonham et al. (2024).

Transformational adaptation building upon a pathways analysis is also emerging, for example, in combination with backcasting (Colloff et al., 2021; Taylor et al., 2023; Werners et al., 2021b). A further extension could integrate a policy pathways analysis with transition theory approaches (Loorbach and Rotmans, 2006) that not only identifies new actions to a desired future, but also indicates what current actions need to stop. This is particularly relevant for pathways analysis supporting climate mitigation analysis, for avoiding new developments in locations exposed to risks, and for building back better or somewhere else post-disaster (Lawrence et al., 2022). Building on this, the idea of opportunities and actions to unlock path-dependencies and how to assess them, would be useful for transformative adaptation.

Climate Resilient Development involves questions of equity, systems transitions towards more sustainable pathways, and enabling conditions (Schipper et al., 2022; Taylor et al., 2023). While we have identified lessons relating to an adaptive pathways approach, the assessment of values and vulnerability and enabling conditions for implementation, little is known about response pathways for achieving the SGD Goals (Malekpour et al., 2023) or for exploring the interaction between mitigation and adaptation (Masson-Delmotte et al., 2023). We found that livelihood and sustainable development considerations are more common in applications in the global south, while in the global north, the focus is mostly on adaptation for maintaining the current system, despite the necessity for transformation and potential for alignment with development.

Monitoring and evaluation frameworks to support adaptive planning exist, and institutional arrangements have been discussed (section 3.3). Applications are emerging but could benefit from more guidance and methods based on real-life applications across more domains, including Indigenous knowledge perspectives, and more actors in the adaptation process. There is still a lack of methods and assessment on what to monitor, how to translate data into signals, the potential timing of signals, and how this informs a pathways plan design, implementation, and reassessment.

Implementation of adaptive pathways plans on the ground continue to face governance and institutional arrangements that are not fit for purpose. Reactive responses to disaster events can crowd out anticipatory adaptation (Mechler et al., 2019). Further research and practice-testing on legal and property rights issues, siloed decision making and funding models that can respond to changing risk, is needed to inform adaptation implementation including. adaptive pathways plans. Fora that can enable exchange of experiences between countries globally about practical adaptation and implementation will also be necessary.

5. Concluding remarks

Over the last decade, adaptive pathways planning has emerged as an approach that can be used to support adaptation decisions. Pathways planning started from academic ideas on adaptation thresholds and the need to sequence actions over time. It was quickly picked up in practice and further co-developed with practitioners in several countries, and is now increasingly being used across the globe to aid real-world decision making.

Our review shows how pathways analyses are being used to help decision makers and other involved parties understand the key factors that drive future adaptation needs and, in light of this, come up with a structured plan specifying short-term actions and long-term options. Moreover, adaptive pathways approaches are used in a wide variety of application domains, including but not limited to coastal sea-level rise and climate change induced changes in flood risk, such as for decisions on infrastructure and transport, agriculture and water management, natural habitat and national park management, for example (Lawrence et al., 2023). The range of real-world cases highlights how the basic idea of adaptive pathways planning is being tailored to domain and context-specific needs, often in conjunction with participatory processes, as well as a rich set of quantitative methods rooted in exploratory modeling and robust decision making. However, there is still a large potential for further application as also concluded by (Magnan et al., 2023). Sharing experiences, including the process and pathways themselves, capacity building and dedicated governance and institutional arrangements can further facilitate applications worldwide.

The review has identified a number of salient points. First, it has become clear that adaptive pathways planning can utilize both qualitative and quantitative methods. There are examples where a set of pathways were initially developed qualitatively using participatory methods and expert input, then followed by more targeted quantitative analysis to elaborate and refine the initial set of pathways. Second, pathways planning is used to connect scenarios describing plausible transient futures with sequences of actions that can be taken in response to how the future could unfold. It thus complements and enriches more traditional scenario planning techniques by explicitly connecting scenarios back to action. Third, optimizing a single pathway for a narrowly defined single objective detracts from the benefits that pathway planning can bring. Fourth, there are tensions between existing guidance for economic appraisal and the use of adaptive pathways approaches. In particular, an assessment of the value of flexibility, building on the real options literature, is needed, along with the assignment of costs to stranded assets and lock-ins, assessment of the opportunity costs and, where possible, quantification of the effectiveness and co-benefits of the adaptation options.

Limitations of current adaptive pathways planning approaches and applications exist. In particular, the increasing complexity of the systems and processes that require DMDU methods, challenge the approaches and methods currently used. Such complexity is derived from value change feedbacks and diversity, multi-actor pathways, interacting pathways for multiple hazards and for climate mitigation and developments, and the need for transformational adaptation. This is currently underrepresented in science and practice. However, the challenge is to include these interactions and develop realistic and implementable pathways to avoid decision paralysis due to complexity. Research developments are emerging (Schlumberger et al., 2022; Taylor et al., 2023), and could be complemented with interactive tools for policy analysts and stakeholders and bringing in knowledge from other scholars (e.g. data visualization and communication, transition experts, anthropologists, psychologists). Moreover, implementation of the results of adaptive pathways planning studies requires further research on fit-for-purpose governance and institutional arrangements.

This paper contributes to the growing literature on adaptive pathways planning by mapping applications globally, analyzing pathways visualization styles and methods, and synthesizing lessons from practice and scientific publications on the value for decision making and a research agenda for ways forward.

Looking forward, key challenges include the use of adaptive pathways planning to support deliberation of pathways for transformative adaptation and climate resilient development. This requires accounting for multiple interacting actors, linking pathways across scales and a better evaluation of equity. We contend that progress on these research challenges can greatly benefit from close interaction between academic research and real-world application.

Author contributions

MH and JL conceptualised the assessment and wrote the first draft. All authors contributed to writing. MH, VDF did most of the data assessment with contributions from JK and JL. JK executed the text mining. JL lead the section on lessons and contributions to decision making. MH and Ilse van den Broek codeveloped the figures.

CRediT authorship contribution statement

Marjolijn Haasnoot: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Valeria Di Fant:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Jan Kwakkel:** Writing – review & editing, Visualization, Software, Methodology, Formal analysis. **Judy Lawrence:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A

A.1. Approach of topic modelling and citation analysis

Latent Dirichlet Allocation, an established and commonly used method to reveal the different topics in the corpus. The basic idea of Latent Dirichlet Allocation is that when authoring a record, an author selects one or more topics to be discussed. Each topic can be expressed using specific words. That is, a record is a mixture of topics, and a topic is a probability distribution over a set of words. Given a corpus, Latent Dirichel Allocation can reverse engineer these distributions and the relative mixture of topics in all records. The number of topics is a user specified parameter. We explored the performance of Latent Dirichel Allocation for a range of numbers of topics, and settled on 8 topics. This offered a reasonable balance between interpretable yet distinct topics, while also being relatively robust to the intrinsic stochastic nature of the Latent Dirichel Allocation algorithm.

For the citation analysis, we extracted the citations from the records. Given that citations information is provided as free text, the same article might be referred to in several ways such as with first author name only or all author names, and full journal title or abbreviated title. So, to disambiguate the citations, we used the Levenshtein distance metric to identify very similar strings and manually inspected them to check if they are the same. The Levensthein distance measures the number of modifications required to turn string a, into string b. After a manual check, we decided to automatically merge all strings where the Leventhein distance was in the lowest 0.25 % and the first author matched. Next, we checked the resulting thesaurus and performed some additional cleaning. For example, if some citations do include the doi, the levensthein distance to a version without doi can be larger than the chosen cutoff point. Manual inspection revealed a number of citations for which this was the case, so we fixed this. Likewise, there were a few cases were the automatic merging suggested merging papers by the same authors and with very similar but distinct titles. These were removed.

Given the cleaned citation data, we created a co-citation network, focussing only on those papers which are cited at least 3 times. Next, we used a community detection algorithm to reveal clusters of papers that are frequently cited together. A community within a network is a group of nodes that are tightly connected with each other, while having significantly less links with other parts of the network. For interpretation, we next identify for each cluster both the top 5 most frequently cited papers, and the 5 papers with the highest eigenvalue centrality within the cluster.

A.2. Questions for the literature assessment

Three main questions and sub questions were guiding the literature assessment:

1) For what purpose and where is an adaptive pathways approach used?
- Why was it used?
- Where and in which policy domain was it used?
- Was this a theoretical or real-world study?
2) How are adaptive pathways assessments done?
- (How) were pathways generated, visualised, and evaluated?
- (How) were decision context (values, knowledge, culture) and institutional arrangements addressed in pathways development and implementation?
- What innovations and extensions of the approach were developed?
3) How has the use of adaptive pathways approaches contributed to decision making?
- What was learned for decision making?
- (How) did it change decisions?
- How were adaptive pathways approaches leveraged by institutional and/or decision-making process changes?

A.3. Feedback from practitioners and decision makers

Examples of practitioners and decision makers feedback on the use of an adaptive pathways planning approach are given in the table below.

Australia	Barnett et al 2014 developed local adaptation pathways with policy actors in a workshop setting and through interviews and conclude: • "The approach we developed was readily understood by, and appealed to, local residents and decision-makers for the following reasons: it is simple (at least relative to other pathways that entail complex sets of options for future action); it creates the time and space for building collective action; it is flexible in the light of new information, technologies, and social and environmental conditions; it accommodates diverse lived values; and it distributes responsibility for decision-making and the costs and benefits of decisions across generations." • "The initial consensus that emerged through this process was sustained by the stepped approach to policy. In the focus groups, even the self-confessed 'climate sceptics' agreed that the proposed initial low-regrets actions to manage the risks of sea-level rise were reasonable precautions, and that the environmental changes associated with each socially-relevant trigger point would demonstrate to them that the environment was changing, and that something needed to be done. Thus linking actions to observed changes helps establish a social licence for actions in the present and the future."
Bangladesh	Personal communication of policy actors working on Bangladesh Delta Plan: • "*BDP2100 Investment Plan has 80 projects clustered in three themes: i) Cluster 0+: Improvement of current system, ii) Clusters 1: Change in current approach and iii) Cluster 2: Change the water system's behavior. Adaptive pathways helped sequencing archetypical projects for each theme, and identifying when a tipping point is reached, necessitating a change from Cluster 0 + to Cluster 1 to Cluster 2 projects.*" By Giasuddin Ahmed Choudhury. • *"We feel very happy that BDP 2100 has been approved by the highest level of authority and the Government of Bangladesh (GoB) has commenced its implementation. BDP2100 has followed the principles of Adaptive Delta Management (ADM), placing a significant emphasis on adaptation pathways as a foundational element. The crucial role and need for these pathways are thoroughly documented in both volumes of the BDP 2100 Main Report. …Moreover, we have conducted extensive training sessions for over 1000 government policymakers, imparting knowledge on ADM principles, including the adaptation pathways. Our commitment to educating policymakers in these principles is ongoing, and we have a detailed training report that underscores the importance of these pathways"*" by Sabbir Ahmed.
Denmark	The guidance on adaptive pathways planning states (Jumppane Andersen et al. (2020): • "*The dynamic planning has been very rewarding and has triggered many reflections. Deliberations and discussions about visions, challenges and options etc. across the entire organization have given us a joint knowledge and understanding, which is a valuable contribution to our continued efforts to create synergy between town planning and coastal protection. The process has contributed to identify possible solutions and their interdependence when it comes to reducing flood risk over time. The process has confirmed that adaptive planning is the way forward.*" By Climate Coordinator Ulla Pia Geertsen, Vejle Municipality. • "*One of the most valuable things about this process is the discussions triggered in our project group when we each take our own professional approach to the area, the challenges and the options. Each individual step in the process has different approaches (for instance risk, visions, options, financing etc.), which forces us to look at the area from different perspectives. In combination with our different professional backgrounds, this makes way for fruitful discussions and new insights into the project area. It is an important process to complete since there are different pathways to choose from and it is important that all professional considerations should be reflected in the solutions chosen*" by Biologist & project manager Katrine Juul Larsen, Assens Municipality.
Los Angeles	Tariq et al 2017 applied robust decision making and discussed adaptive management and pathways with stakeholders: • "*some stakeholder groups express distrust with adaptive management because they perceive it as a means to defer hard but uncertain decisions to the future without any means for current stakeholders to commit their successors to taking action in the future if needed.*"
Netherlands	In the context of the Delta Programme the following statements are made related to their use of a pathways approach: • "*Development pathways or adaptation pathways offer a strong approach to show which options are needed and when they should be implemented and how long-term objectives influence short-term decisions.*" (Delta Programme, 2012) • Wim Kuijken, former chair of the Delta Programme (Kuijken, 2011): "*One of the biggest challenges is dealing with uncertainties in the future climate, but also in population, economy and society. This requires a new way of planning, which we call adaptive delta planning. It seeks to maximise flexibility; keeping options open and avoiding 'lock-in'*". Note that in the NL the adaptive pathways approach is incorporated in the concept of adaptive delta management. • Bloemen et al 2018: *"The large-scale survey in the Delta Programme in 2013 showed that 72 % of all respondents agreed that the Delta Programme was successful in connecting short-term decisions with long-term objectives, one of the four goals of Adaptive Delta Management. The use of adaptation pathways, facilitating future switches between strategies, was judged positively by 47 % of the respondents."* Haasnoot et al 2013b developed pathways in joint consultation with water managers involved in the Delta Programme using storylines as narratives of plausible futures including climate change, socio-economic developments and policy actions. The storylines were combined and plotted on an adaptation map. • Page 185: "*This helped the managers to get a better picture of how pathways could emerge. The results also pointed out the participants' preferences for specific actions, and raised awareness about potential 'tunnel-visioning'.*" • Page 178–179: "*In the storyline design session for the Delta Programme, participants mentioned that the approach helped to identify key decisions and potential lock-ins. Developing storylines made participants aware that they had implicit preferences for riverbed widening and levee height the Rhine delta case raising strategies, and that actions related to spatial planning must be considered as well. Other feedback indicated that for some, the Pathways approach was slightly difficult to understand. These individuals found the storylines helpful in understanding the pathways.*"

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New Zealand	Lawrence and Haasnoot 2017 discussed the impact of a DAPP game session on participants perspectives about adaptive planning under uncertain and changing conditions and for their decision making: • "We make short-term decisions."..''This [DAPP] game showed we can make long-term decisions by anticipating and adjusting." • "We got better results through negotiation with the other groups." • "We experienced uncertainty and could chart a pathway." After the Game, the Greater Wellington Regional Council flood managers championed the DAPP for use in other projects (See Box 1, p54 of the paper), and for capability building.
Portugal	Campos et al 2016 interviewed policy makers and other stakeholders after pathways design workshop and summarized the responses: • *"on long-term planning: The need for a long-term planning is valorized; learned that potential adaptations refer to various technical options; learned that a wide range of costs needs to be studied; demystified assumptions regarding engineering interventions.* • *on participation: Workshops provided a collaborative forum for discussion; promoted mutual understanding among participants; conveyed the meeting of different knowledge systems and experiences; visual materials delivered a clear understanding of possible future risks; social learning experience, replicable in their own institutions. It is very different from "the real world".* • *on implementation: Technical studies for proposed engineering interventions (*e.g. *detached submerged breakwater). Economic assessments of different technical options for measures (*e.g. *cost-benefit analysis) engage media and society at large, dissemination and awareness raising."*
Singapore	The government of Singapore has adopted a pathways approach for coastal adaptation (https://www.pub.gov.sg/Public/KeyInitiatives/Coastal-Protection): • "… it is imperative to start preparations now to formulate plans and implement them progressively as development of coastal protection measures requires long lead-time and substantial investment. To cater for uncertainties, PUB's coastal protection strategies will have to be flexible to allow for adjustments according to new developments in climate science." • "…Through the use of adaptation pathways in PUB's strategy, our coastal protection approach ensures adequate protection while retaining the ability to adapt to changes in climate projections."
Sweden	Carstens et al 2019 concluded after an adaptive pathways planning application through three workshops for three case municipalities: • "The results show that the approach promoted vulnerability-based thinking among the end-users and generated new ideas on how to manage the uncertain long-term impacts of future sea-level rise." • "Based on feedback from the participants, we concluded that the method's capabilities to incorporate large uncertainties were appreciated, and a general comment was that the participants left the workshop series more confident about dealing with these uncertainties and with the knowledge that they are manageable." • "Participants in all three case studies indicated that the work provided some crucial insights into the climate-related uncertainties that were not known prior to the workshops. Another interesting result, strengthening the argument that the method did initiate creative processes and cross-fertilisation between professions, was that all the groups developed actions and pathways relevant to real problems that they were not aware of before the workshops."
United Kingdom	• Bloemen et al. 2018: "*The London Climate Change Partnership has advocated for the use of pathways approaches and the London Assembly has called for the mayor to "formulate options for adaptation, grouped where appropriate into 'pathways' of linked adaptation"(London Environment Committee (LEC)* 2015, p.27). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6105246/ • Kingsborough et al. 2016: "*Initial stakeholder feedback found the pathways diagrams to be a potentially valuable input to long-term planning… Stakeholders found that our method created a 'free thinking space' for the unrestricted consideration of actions that may not be politically or financially acceptable in the near-term. In this thinking space, the implications of prioritising flexible actions as a means of achieving robust outcomes can be explored in focus group discussions."*

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