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ORIGINAL ARTICLE

Transition pathways to sustainability in greater than 2 °C climate futures of Europe

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Abstract

The complex challenges arising from climate change that exceeds the +2 °C target (termed 'high-end climate change') in Europe require new integrative responses to support transformations to a more sustainable future. We present a novel methodology that combines transition management and high-end climate and socioeconomic change scenarios to identify pathways and move Europe closer to sustainability. Eighteen pathways have been co-created with stakeholders through a participatory process. The pathways support Europe in moving towards a desirable future vision, through top-down and bottom-up actions that lower greenhouse gas emissions, reduce impacts of and vulnerabilities to climate and socioeconomic changes and enhance well-being. Analysis shows that the pathways that are robust to future scenario uncertainty are those that shift Europe towards sustainable lifestyles, support and strengthen good governance for sustainability and promote adaptive resource management for water, agriculture and energy. The methodology can support the design of the urgent actions needed to meet the requirements of the Paris Agreement and to transform Europe, in preparation for an uncertain future.

Keywords Climate change · Pathways · Adaptation · Mitigation · Transformation · Transition management

Abbreviations

CAP	Common Agricultural Policy
EU	European Union
IAP	Integrated Assessment Platform
RCPs	Representative Concentration Pathways
SSPs	Shared Socioeconomic Pathways
WFD	Water Framework Directive

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Introduction

Despite the Paris Agreement to avoid dangerous climate change, it is increasingly plausible that the global increase in mean temperature will surpass the 2 °C threshold (IPCC 2014; Stafford Smith et al. 2011). Temperature increases above 2 °C, referred to in this paper as 'high-end' climate change, are likely to lead to detrimental environmental, social and economic consequences and to the emergence of critical thresholds that tip current social-ecological systems into another (probably less socially desirable) state with largely unknown consequences (Steffen et al. 2015, 2018; Rockström et al. 2009; Russill 2015). Limiting, as well as coping with, high-end climate change will demand the balancing of mitigation (reducing the emissions of greenhouse gases), adaptation (making society less vulnerable to climate change by responding to immediate impacts) and transformation (fundamental, deep, systemic changes to institutions), as well as acceptance of residual damages (Tinch et al. 2015). Responding to high-end climate change requires climate mitigation and adaptation actions that are not simply technological fixes and that do not only address one isolated issue at a time. To respond to high-end climate change, the actions must

also contribute to transformations towards a more sustainable future (Gillard et al. 2016; O'Brien and Selboe 2015). Addressing climate change in this way facilitates long-term, integrative approaches that recognise synergies and trade-offs between multiple goals associated with societal well-being (McHale et al. 2015; Pelling et al. 2015) which can overcome path dependencies and lock-ins (Hermwille 2017; Meadowcroft 2009; Shaw et al. 2014).

Addressing the challenges from high-end climate change in Europe (Harrison et al. 2019) requires actions that also create the necessary conditions for their implementation. To identify such actions, we use a pathways approach. Pathways are bundles of strategies and actions that support the achievement of a long-term vision. The approach has been used in other studies (Rosenbloom 2017; Wise et al. 2014) since it aids thinking about actions for responding proactively to complex problems like climate change (Frantzeskaki et al. 2012a; Leach et al. 2010; Tabara et al. 2018; Wise et al. 2014) while considering the synergistic and progressive effect of short-term, medium-term and long-term actions (Frantzeskaki et al. 2012b). The pathways approach has been adopted within climate change research to enable policy-relevant research (Haasnoot et al. 2013; Wise et al. 2014) from an integrated systemic perspective (Leach et al. 2010; Turnheim et al. 2015) and with an explicit normative orientation (Ferguson et al. 2013; Frantzeskaki et al. 2012b; Geels et al. 2016; Rosenbloom 2017, p.39). The use of a long-term vision as the endpoint of the pathways provides strong guidance regarding the actions that need to be taken, and the pathways demonstrate the multitude of actions needed for a more sustainable future (Luederitz et al. 2017). Furthermore, pathways can position actions in response to climate change in relation to, and not separate from, social, cultural, political, economic and institutional contexts (Foxon 2013; Haasnoot et al. 2013; Nevens et al. 2013; Rosenbloom 2017; Wise et al. 2014).

In this paper, we present and apply a novel methodology for developing pathways within the context of high-end climate and socioeconomic change scenarios ("Methodology") and their inherent non-linearity and deep uncertainty (Tabara et al. 2018). It is the first time the pathways methodology has been advanced in such a way to be applied in the context of high-end scenarios, and given its application and results, we contend that it is a novel way to initiate policy guidance for climate change in high-end scenarios. The results of using this methodology are presented and analysed in the "Results" section. The pathways, co-created through a participatory process with diverse yet representative European stakeholders, not only link climate change adaptation and mitigation and include a mix of sectoral strategies but also include transformational actions and solutions (Abel et al. 2016; Foxon 2013). We analysed the pathways to identify those which are robust over a broad range of plausible socioeconomic and climatic conditions given the uncertainty associated with high-end climate change in supporting the achievement of the vision. Our analysis shows that three pathways ((a) lifestyle changes, (b) sustainability governance and (c) integrated resource management) can be found in all four of the climate and socioeconomic scenarios used in this study and are thus considered to be robust. In the analysis of the pathways, we also identify synergies and trade-offs between different actions and strategies, as well as the institutional conditions and the actors required to implement them. After the discussion of these results in the "Discussion" section, we conclude in the "Conclusions" section with a short assessment of the usefulness of this new approach to the co-creation of pathways.

Methodology

We adapted the transition management methodology (Frantzeskaki et al. 2012b, 2018) to consider high-end socioeconomic and climate scenarios as the contexts in which pathways of action are co-created. In doing so, there are five main stages to the development and evaluation of pathways that support long-term, transformative change towards a sustainable and resilient future for Europe:

(1) Stakeholders from government, business and industry, civil society and research were systematically identified via a stakeholder mapping exercise (against key sectors, geographical scope of activity, organisational affiliation, age, gender), ensuring a minimum quota for each category. For further information on this stage, see Gramberger et al. (2015) and the Electronic Supplemental Material A;
(2) Stakeholders, with support from the research team, developed a multi-faceted, shared vision of Europe in the 2100 that forms the normative and scenario-independent goal for the pathways;
(3) Stakeholders formulated (different types of) actions (adaptation, mitigation and transformation) using moderated backcasting from the vision to a future contextual scenario, taking account of likely scenario-specific impacts and vulnerabilities (as opposed to backcasting to the current situation). The result was sets of actions for four different contextual socioeconomic scenarios (using downscaled Shared Socioeconomic Pathways, SSPs) and matched climate scenarios (using downscaled climate projections under the Representative Concentration Pathways, RCPs);
(4) The stakeholders clustered the actions. Some of the clusters were sectoral (e.g. agriculture, water, energy, healthcare), while others were cross-cutting (e.g. lifestyles, governance, education). The research team used these clusters to develop proto-pathways that include sectoral and cross-sectoral strategies to achieve the same element of the vision. Every strategy includes actions

that address both short-term and long-term impacts of climate and socioeconomic scenarios. Further enrichment of the pathways by the stakeholders during a second workshop resulted in sets of pathways for the four different scenarios;

(5) The research team made a comparative analysis of the pathways to identify pathways' inter-dependencies and robust pathways across all four scenarios.

Collaborative knowledge generation for the vision and pathways took place in two participatory workshops, each lasting 2.5 days. The first workshop focused on the following: finding a common agreement on the vision elements that the stakeholders had identified prior to the workshop in an email survey; evaluation of the likely performance of existing European policies in the future contextual scenarios; identification of actions per scenario that would contribute to achieving the vision and avoid trade-offs; and clustering of actions. After the workshop, the research team created 'proto-pathways' from the clustered actions. During the second workshop, the stakeholders enriched the proto-pathways with additional actions to improve their efficacy in achieving the vision. The collective knowledge generation culminated in the production of a suite of interrelated pathways for each context scenario. A detailed description of the methodology for developing and analysing the pathways[1] is given in the Electronic Supplemental Material A and briefly described below (Fig. 1).

Scenario-independent vision for Europe in 2100

A vision for Europe in 2100 was developed through an iterative process of engagement with the identified stakeholders. An email survey elicited the key elements of the stakeholders' vision of the world they would like future generations to see in 2100. The research team clustered and analysed these elements before the first workshop. The stakeholders provided their feedback on the first version of the vision during the workshop and the research team subsequently revised the vision. At the second workshop, there was further iteration of feedback and revision of the vision elements and narrative statements (see Fig. 1). The final agreed vision provides a rich narrative of a desirable state of European society that integrates socioeconomic and environmental elements. The vision is given in full in the Electronic Supplemental Material B and key elements in Table 1.

Context scenarios

The four scenarios used as context for the pathway development combine downscaled climate scenarios based on the Representative Concentration Pathways (RCPs, van Vuuren et al. 2011) and socioeconomic scenarios based on the Shared Socioeconomic Pathways (SSPs, O'Neill et al. 2013). These scenarios describe what Europe could look like in the future. The scenario development process is described in this issue by Kok et al. (2019). The selection of SSPxRCP combinations made by the research team considers the following:

(i) The RCPs are high-end, with the European average temperature change greater than 2 °C, which is the case for both RCP4.5 and RCP8.5;

(ii) The SSPs cover a broad range of possible socioeconomic challenges to mitigation and adaptation, which is the case for SSPs 1, 3, 4 and 5; and

(iii) The combination of SSPs and RCPs provide 'integrated scenario contexts' that capture both climate and socioeconomic drivers.

The research team developed the socioeconomic storylines for the context scenarios building on work in a previous European project (we refer to Kok et al. 2019) and the global SSPs (O'Neill et al. 2013). The scenarios describe alternative contrasting, divergent and plausible futures, and capture a broad range of the inherent future uncertainty. The combination of the four integrated scenarios entails that the SSPs with highest fossil-fuel intensity (SSP5 and SSP3) are combined with RCP8.5, while renewable-driven scenarios (SSP1 and SSP3) are matched with RCP4.5. We refer to Kok and Pedde (2016) for the full European SSP narratives. The scenarios we refer to in the rest of the paper are SSP1, SSP3, SSP4 and SSP5. Key elements of the context scenarios are presented in Table 2.

Actions and transition pathways

The stakeholders identified actions to achieve the vision for each context scenario based on (i) the scenarios, i.e. which actions we need to respond to the climatic and socioeconomic changes in the context scenarios; (ii) the modelled climate change impacts (e.g. Harrison et al. 2019), i.e. which actions we need to take to respond the expected impacts; and (iii) the stress-testing of current major European policies (e.g. The European Union's Common Agricultural Policy, the Water Framework Directive), i.e. which actions we need to take to modify current policies, so that they continue to support the achievement of the vision. During an intermediate analysis step (step C, Fig. 1), the research team screened the actions from the stakeholders using the narrative matching analysis method (Goffman 1974; Entman 1993). The screening identified some proposed actions that were vision statements or additions to the scenario storylines. These were included in revising and further enriching the vision and scenarios and were not used in formulating the pathways. To draft the first

[1] Further detailed information on the methodology and results is also available here: http://www.highendsolutions.eu/page/lightblue

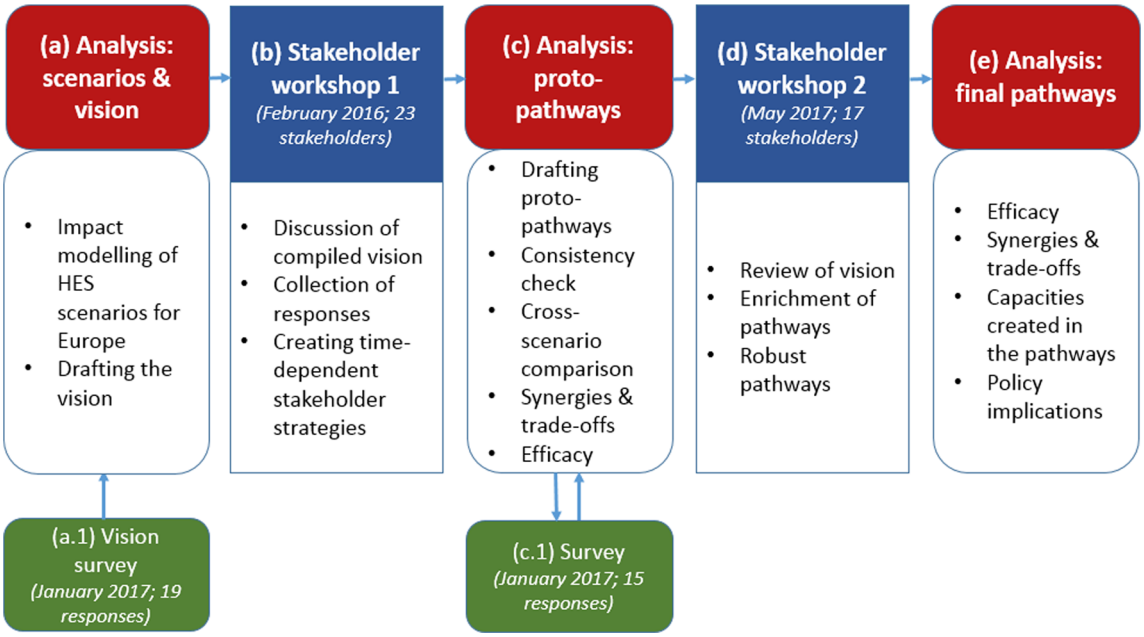

Fig. 1 Process steps to co-create transitions pathways for Europe under high-end climate change

version of the proto-pathways, the research team analysed the actions collected at the first workshop following the objective-driven inquiry method from operations research (Keeney 1996). In the second workshop, stakeholders enriched the pathways to improve their efficacy in achieving the vision and to avoid or minimise any likely trade-offs identified by the research team.

Comparative analysis of the pathways across scenarios

The research team analysed the final pathways within and across scenarios with regard to (a) the conditions that the pathways create for their effective implementation, (b) synergies and trade-offs across pathways within each scenario, and (c) the robust pathways across scenarios and their interrelationships (see Electronic Supplemental Material A for more detail).

Results

In the following section, we present an overview of the pathways. The full vision narrative and pathways are given in Electronic Supplemental Material B. We first show that the pathways in each scenario follow a distinctly different logic, because the contextual scenario storylines allow certain

Table 1 Key elements of the stakeholders' vision of Europe in 2100

Living and lifestyles
- High quality of life
- Healthy people
- Self-sufficient communities
- High-density living
- Basic human needs met
- Solidarity
- Advanced and affordable education

Voice, equity and equality
- Equity among citizens and societies
- Wealth duly distributed
- Poverty eradicated

Governance
- New modes of governance
- Democratic values
- Europe is strong, peaceful and cohesive
- National and regional diversity
- Collective goals
- Unified in the face of challenges

Environment
- Balance in preserving and using ecosystem services
- Respect planetary boundaries
- Resources used efficiently

Food, water and energy
- Zero CO_2 emissions
- High dependence on renewables
- Sustainable agriculture and fisheries
- Food security for all
- Sustainable use of water

Resilience
- Acting pre-emptively
- Striving to prevent crises
- Disaster risk plans widely available

Table 2 Key elements per European SSPxRCP context scenarios (adapted from Kok and Pedde 2016) SSP refers to the socio-economic scenario. RCP refers to the climate scenario used in combination with the socio-economic scenario. European climate change is indicated by the difference in average temperature (ΔT) and in average precipitation (Δpr) between 1961-1990 and 2071-2100 (derived from climate modelling results, see Madsen et al. 2016)

Key elements	SSP1: Sustainability – we are the world	SSP3: Regional rivalry – Icarus	SSP4: Inequality – riders on the storm	SSP5: Fossil-fuelled development
RCP	4.5	8.5	4.5	8.5
European ΔT/Δpr[1]	2.4 °C/1%	4.8 °C/8%	2.4 °C/1%	4.8 °C/8%
Challenges to mitigation	Low	High	Low	High
Challenges to adaptation	Low	High	High	Low
Decision-making level	International/ EU leader	National/Local+ fragmentation	International/Europe leader on the global scale	International/EU not a leader on the global scale
International cooperation	Strong, EU important player	Weak	Strong, EU important player	Strong (trade)
Net migration- low in-- migration	Low immigration	Outmigration	Selected immigration	High to cities and from poorer countries
Economic development	Gradual (with volatility at the beginning)	Low	High	High
Mobility	No barriers, but movements are limited	Low	High	High
Social cohesion	High	Low EU/higher within countries	Low	High
Technology development	High, but not pervasive	Low	High in some areas; low in labour intensive areas	Strong and crucial
Quality of governance	High – focus on sustainability	Low and ineffective	High and effective	High – focus on businesses
Human health investments	High	Low	High for elites	High
Education investments	High	Low	High for elites	High
Environmental respect	High	Low	Locally high	Low

[1] European change in temperature (ΔT) and precipitation (Δpr) in 2071–2100 relative to 1961–1990 (derived as average from GCM-RCM scenarios within IMPRESSIONS IAP2

actions and limit others. We then show that there are three pathways that are common to all scenarios: shifting to sustainable lifestyles, supporting or strengthening good governance for sustainability and promoting adaptive resource management for water, agriculture and energy. Analysis of the pathways then looks at the differing roles of the main actors—government, civil society and market actors in implementing the pathways in the different scenario contexts. Finally, we examine those pathways that either support the implementation of others or lead to trade-offs with other pathways.

Pathways

A total of 18 pathways were formulated across the European context scenarios, with 4–5 pathways per context scenario. They focus on governance, leadership, lifestyles, technology development and innovation as well as resources management including water, land and biodiversity. The pathways are summarised in Table 3. The pathways follow scenario-specific logics because each context scenario provides differing opportunities for, and constraints to, actions, so:

- SSP1: The pathways build on the high level of governance capacities (see "Agency, Capitals and Capacities") in this scenario and especially international, multi-level and bottom-up governance, technological innovation and learning (e.g. in governance and education), as well as behavioural and market changes.
- SSP3: The pathways are developed, in the face of weak and fragmented governmental institutions and an overall lack of resources, with an underlying motive of moving to local, circular economies and a decentralised, networked local community governance system.
- SSP4: The pathways start from different needs and abilities in the two-layered (elite and majority) society in this scenario. The elite has an interest in the sustainable management of resources and the ability to invest in green innovation. In contrast, the pathways for the majority of the population organise alternative economies and mechanisms for fostering resilience through local networks.
- SSP5: The underlying logic of the pathways is to use the dominant market-based orientation of the scenario to protect ecosystems and to integrate environmental protection into business practice while remaining economically efficient.

Table 3 European transition pathways across SSPs, scenario-specific strategies and examples of actions (SSP1, SSP3,SSP4 and SSP5 refer to the four scenarios used in the study; CAP is the Common Agricultural Policy; WFD is the Water Framework Directive; SME refers to Small- and Medium-Enterprises:; and ICT refers to Information and Communication Technology)

Pathways across SSPs	Exemplar scenario-specific strategies relating to pathway	Examples of specific actions (within SSPs)
A) Promote shifts towards sustainable lifestyles	Facilitate behavioural changes and well-being oriented policy for sustainable lifestyles and well-being [SSP1]	*Reduce car dependency by increasing public transport, biking, car sharing options *Local energy production and consumptions with solar roofs *Add sustainability to civil classes > exemplary schools, administration etc.
	Foster awareness raising on sustainable lifestyles and social cohesion [SSP3]	*Strengthen local initiatives – to live with less *Support sharing economy (using ICT, social media – communication) *Re-establish economic co-dependence and co-operations in regions
	Establish value-based education and incentives for sustainable lifestyles and fair distribution of resources [SSP4]	*Set-up process-oriented society based on learning and monitoring *Implement education and awareness campaigns for waste reduction (e.g. packaging) *Provide minimum wage for everybody
	Foster consumer awareness and invest in education and research for sustainable production and consumption [SSP5]	*Introduce circular economy principles *Invest in education for nature to create a mind-set for nature *Invest in bio-based economy research and other technologies (who: business)
B) Promote good governance systems for sustainability	Establish open and experimental governance for sustainability [SSP1]	*Strengthen EU-citizen connection, reinforce EU democracy *Establish more participative processes for sharing decisions across levels (bottom-up) *Develop new governance technology: massive research and application
	Establish local and community-based governance and infrastructure for local self-organisation and networks [SSP3]	*Strengthen democratic inclusiveness and transparency *Protect role of experts in decision-making processes *Strengthen open communication infrastructure for citizens
	Establish multi-level, process-based governance for sustainability and European self-sufficiency [SSP4]	*Set up data-based and evidence-based governance *Set up monitoring system of the evidence from the implementation of the master plan *Formulate regulation to establish a single energy market in Europe including distribution of energy infrastructure
	Establish and support participatory governance for sustainability [SSP5]	*Guarantee that satisfaction of basic human needs are not subject to the market *Change the indicators of prosperity to include human development *Increase participation of decision-making to research and knowledge processes
C) Promote sustainable agriculture	Mainstream sustainable agriculture through scaling the Common Agricultural Policy (CAP) and invest in new agriculture technology [SSP1]	*Support climate friendly farming: leg-crop action recycling, agroforestry and tillage *A CAP pillar that incentivizes and rewards environmental and socio-economic services to be 100% EU financed *Set urban agriculture target in CAP: production targets from urban agriculture and part of urban planning policy
	Support skills for local organic agriculture and ecosystem service regeneration [SSP3]	*Provide incentives for environmentally friendly local agriculture *Identify and protect ecological corridors and increase natural protected areas *Promote bio-refineries to mitigate climate change *Employ SME-instrument for family-owned agriculture (who: EU to employ)

Table 3 (continued)

Pathways across SSPs	Exemplar scenario-specific strategies relating to pathway	Examples of specific actions (within SSPs)
	Design an integrated organic agricultural system to increase food security by scaling the CAP and incorporating ecosystem services' values [SSP5]	*Introduce irrigation water management technologies *Continue integrated farm management and organic agriculture (scale CAP over time)
D) Promote strong environmental policy	Promote holistic nature protection and restoration by mainstreaming ecosystem services and nature-based solutions into regulation and planning [SSP1]	*Integrate ocean resource planning *Introduce different models of agroforestry all over Europe *Re-nature rivers and reconnect with flood plains
	Strengthen biodiversity protection and land-use planning in harmony with nature [SSP4]	*Establish new protected and provide space for leisure (e.g. natural parks) *Set up local sustainable food production with parks to create new jobs at the European level considering regional and local contexts *Develop central strategic plans for the continent based on knowledge about areas that are prone to flooding
	Creating nature-based markets that push for technological innovation and account for ecosystem services [SSP5]	*Integrate value of ecosystem services in economic decisions to select what can work in management for land *Introduce higher taxes for fossil fuels *Set up funds to deal with climate impacts
E) Promote integrated water management	Strengthen physical and social resilience to protect from floods and droughts [SSP3]	*Combine river-flow interventions with clearance of rivers *Link CAP with WFD objectives: less water-intensive crops have financial incentives *Household rain harvesting for specific uses
	Implement integrated adaptive water management across Europe [SSP5]	*Adapt and reinforce control measures for water quality and water pollution *Invest in effective and efficient water technologies *Give space to the rivers programs in Europe
F) Position Europe as a global leader for sustainability	Position Europe as a global leader for sustainability [SSP1]	*Implement stronger EU solidary mechanisms *Develop clear EU-wide sustainability vision and more effective communication *Set compulsory building codes for flood resilient houses
G) Establish a circular economy with green energy technologies	Strengthen Europe's market position in developing and applying green technologies for water efficiency and sustainable energy [SSP4]	*Move from local to regional energy provision and generation *Promote development of virtual regional energy grids for green energy distribution *Move towards global European energy grids – implementation of cross-border connections

The private sector realises the need for protecting the resources upon which the economy depends in the long-term and pushes for change.

Cross-scenario analysis of pathways

Across scenarios, many similar pathways and proactive and reactive actions are proposed to support achieving the vision (Table 3).

From the cross-scenario analysis, we observe three common directions of action in the pathways: shifting to sustainable lifestyles (pathway A across all scenarios), supporting or strengthening good governance for sustainability (pathways B, D and F including strong environmental policy) and promoting integrated and adaptive resource management for water, agriculture and energy (pathways C, E and G). We refer to these three common broad pathways as robust pathways.

Across all scenarios, shifting to sustainable lifestyles is recognised as a pivotal pathway (pathway A in all scenarios). Participants argued that, to deal with high-end climate change, European societies need to address their ways of living in terms of resource and energy footprints. However, resource considerations are not the sole focus of pathways of shifting lifestyles. They include education and awareness-raising activities to enhance consideration of the environment and social equity and cohesion. Education is also introduced to provide the population with the skills (practical, creative, decision-making etc.) needed for the future ahead. For example, a strategy in SSP3 (SSP3xRCP8.5) serves to foster social cohesion among impoverished local communities by providing social support to unemployed people (e.g. revenue, training) and

strengthening local initiatives. SSP3 supports sustainable local communities through supporting innovative entrepreneurship, diversifying economic activities, developing alternative economies (e.g. bartering) and establishing regional economic co-dependence and cooperatives. Especially in the SSP3 and SSP4 scenarios, which are characterised by rampant inequality, shifting to sustainable lifestyle pathways includes actions towards institutional and cultural conditions that improve equity and social security in Europe. In SSP1, actions promote public and private investments in new infrastructure and technology to, for example, support intermodal mobility (to curb car dependency) and promote decentralised renewable energy production.

Building on the conditions in their respective scenarios, all scenarios include a pathway to set up participatory, multi-level and transparent governance structures (pathways B, D and F), which facilitate coordination and collaboration across sectors in Europe. In the SSP1 scenario, the good governance pathway strengthens the existing multi-level governance structure and international collaboration that in turn serves to achieve Europe's global leadership agenda on sustainability. Multi-level governance structures help to manage resources at local and regional levels in relation to context-specific needs and opportunities while connecting them to the European sustainability agenda. This is equally visible in the SSP4 pathways, in which the European elite strategically coordinates the implementation of a master plan to guide and coordinate all developments, but regions and communities are interconnected to support each other and build on each other's assets. Inclusive and participatory governance structures enable civil society to actively participate in political discourses and decision-making at international, European, national, regional and local levels. To ensure that actions are in line with social and environmental conditions and to prepare for risks, the pathways put in place comprehensive data and knowledge monitoring systems. For example, the planning approach in SSP4 relies on a new type of evidence-based governance system that sets up continuous monitoring and learning to oversee and adapt the proposed European-level master plan. In the SSP5 scenario, research, innovation and decision-making shift from sector-based to problem-based, supported by monitoring approaches, which underpin new institutions for integrating environmental concerns into long-term cost-benefit calculations.

There is a strong emphasis on integrated policy and planning frameworks to guide political, social and economic behaviours, develop multi-functional solutions and take synergies and trade-offs between different sectors into consideration for all scenarios, except the SSP3 scenario. This integrated perspective is manifested in the types of solutions suggested for sustainable water management, such as water-sensitive infrastructure systems for water quality and quantity conservation in relation to agriculture, biodiversity, land use, energy, recreation and climate adaptation. In the SSP4 scenario, this strategic orientation is defined top-down in the form of a master plan. The plan takes a birds' eye perspective on context conditions, opportunities and needs of European regions, building on the notion of a 'small ecosystems' approach'. The integrated policy and planning perspective is manifested in the formulation of integrated framework conditions such as regulations, incentives, taxes and (self-regulated) financing mechanisms that enable long-term decisions and investments to build synergies across sectors and dis-incentivise unsustainable practices in all scenarios. Specific actions include the setting up of a carbon tax, regulation to mandate that corporations re-invest profits into communities and subsidies to community green energy schemes. For example, the European SSP5 pathway for stronger environmental protection proposes nature-based markets that account for the cost of nature, integrate the value of ecosystem services into economic decisions and set up funds to deal with climate change impacts. In the SSP3 scenario, this strategic orientation diverges due to the weak government in this scenario that implies there is no governance ability to put in place integrated policy and planning after 2040. As a result, the governance pathway focuses on strengthening local communities that collaborate within regionally connected networks to exchange knowledge and resources.

Pathways emerged within all scenario contexts to shift towards adaptive, context-sensitive and integrated resource management (pathways C, E and G) that considers planetary limits are organised on interconnected local and regional levels and support European self-sufficiency. Different sectors are emphasised across scenarios: agriculture (SSP1, SSP3, SSP5), water (SSP3 and SSP5) and energy and circular economy (SSP4). The resource pathways build on integrated environmental standards and planning frameworks to enable multi-functional solutions. Regarding agriculture, multi-functional and integrated farming is proposed that builds on the EU's Common Agricultural Policy (CAP) and national policies to produce different types of food and other services. Resource pathways include strategies that aim to develop, or, mainstream technological innovations for achieving resource efficiency and security and environmental protection, such as innovations in renewable energy technology (in line with the European Union Energy strategy for 2020), water efficiency technologies and nature-based solutions. Technology-based strategies in the SSP3 pathways focus largely on local, low-tech innovations for infrastructure improvements that in turn allow local network economies to exist. In contrast, in the SSP4 and SSP5 pathways, technology-based strategies develop large-scale green technological innovation. This reflects the high-level of technological development in these scenarios. The SSP4 pathway invests in the expansion of renewable energy technologies while ensuring effective energy distribution and energy security. Another key pillar in the resource management pathway is the mainstreaming of nature-based solutions to maintain natural capital in the long-term, to ensure resource quality and security and to enhance resilience. For example, the pathways for SSP3 include actions to create green cities and implement rainwater harvesting in households. Finally, skills and knowledge

transfer—building on pathway A—support changing resource management practices (e.g. community-based and climate-friendly farming). The SSP5 pathway includes awareness raising for the agricultural sector on land degradation and resulting losses in yields and profits. Such actions can develop further the European Union Biodiversity Strategy, and it was mentioned by the stakeholders that enrichment and strengthening of the Common Agricultural Policy can be guided by the proposed actions. Furthermore, the SSP5 pathway identifies the role of citizens' knowledge for participating in local agriculture and environmental restoration.

Agency, capitals and capacities

There are differences in both the capitals and governance capacities that are available in the context scenarios. The capitals (social, human, manufactured, financial and natural) refer to the system conditions available in a scenario to support the pathways—such as, for example, institutional conditions, financial resources, soil and water. The governance capacities refer to the abilities of actors to mobilise and use capitals to implement the pathways and, through their effective implementation, to also enhance the availability of capitals for achieving the vision. Different types of actors are differentially enabled to act in each context scenario (Table 4). Across scenarios, all pathways build on strong governmental actors that provide regulation, coordination, incentives and financing, although they play a considerably smaller role in the SSP3 scenario. The pathways in the scenarios (except for the SSP3 scenario) build (on) a strong EU that has good international as well as civil society relations and works within a multi-level and decentralised governance structure. The governance systems put in place long-term, synergistic and integrated framework conditions that enable long-term decisions and investments to create synergies across sectors and to disincentivise unsustainable practices. For example, in the SSP5 scenario, the costs of environmental degradation and the intrinsic value of nature are internalised into economic activity, which serves to adapt prices and promote investments in green technologies.

Civil society plays a critical role in the pathways of all scenarios, being actively involved in decision-making and in the development and implementation of action (e.g. sustainable consumption, local renewable production, environmental and basic education). In the SSP3 scenario, civil society and entrepreneurs act at local community levels given the lack of government capacity. In the other scenarios, civil society is actively involved through inclusive, participatory and transparent governance structures at regional and local levels and, in SSP1 and SSP5, at European and national levels.

Market actors (industry and business actors) and knowledge institutions have important roles in the pathways of all scenarios. Market actors play a fundamental role in SSP5 in the re-orientation of market activity to integrate long-term environmental costs. The pathways in all scenarios highlight a shift towards small- and medium-sized and family-owned companies to avoid monopolies, facilitate local and diversified economies and ensure equality. Actors from knowledge institutions (e.g. universities, research institutes) are implied in actions to implement better monitoring and research on environmental and social problems and solutions and to set up process-based governance approaches.

Interdependencies and trade-offs between pathways

Analysis of the pathways in all scenarios shows that the pathways are strongly linked and support each other in contributing towards the vision. However, two robust pathways provide the foundations for the other pathways across all four contextual scenarios: the pathway that promotes shifts to sustainable lifestyles and the pathway that promotes good governance for sustainability. Consequently, achieving the vision is unlikely without successful implementation of these pathways in any future scenario.

Shifting to sustainable lifestyles (pathway A) underpins changing resource use and demand for sustainable products and technologies. The pathways affect multiple sectors, relating to actions about water and energy consumption, food and agriculture practices, trade approaches and production processes. Shifting to sustainable lifestyles pushes for mainstreaming of sustainable agriculture that respects the environment, as there will be higher demand, incentives and obligations for sustainable products and production approaches. Likewise, lifestyle shifts support integrated water management in the SSP3 and SSP5 scenarios, because there will be less water use and more water re-use.

The pathways of good governance for sustainability (pathways B and D) support the organisation, use and delivery of services in the other pathways. For example, the good governance pathway (pathway B) supports setting up integrated water management systems in the SSP3 and SSP5 scenarios, by providing institutions and frameworks for developing policies and land use management systems. In the SSP4 scenario, it generates a framework in the form of a master plan and identifies the conditions for its top-down implementation. This enables the setting up of a European circular economy that closes loops at multiple scales.

As an example of the foundational role of these underpinning pathways, the development of good governance approaches for sustainability policies within pathway B for the SSP1 scenario supports the implementation of all other pathways. Establishing open governance approaches for strengthening sustainability policy directly supports strong environmental policy (pathway D), shifts to sustainable lifestyles (pathway A), strengthens the positioning of Europe as a global leader for sustainability (pathway E) by defining (in

Table 4 Agency capacities in scenarios and in pathways for Europe

	Key elements	SSP1: Sustainability - we are the world	SSP3: Regional rivalry - Icarus	SSP4: Inequality - riders on the Storm	SSP5: Fossil-fuelled development
Scenarios	Key actors in scenarios	All societal actors (government, market, civil society) at multiple levels	No EU after 2040 and weak governments; rich corrupt market actors; local communities self-organise	Small political and business elite concentrates power and resources; majority of the population in local communities	Government and market actors
	Agency capacities in scenarios	High ability to act – sustainability strategies and institutions, multi-level governance and participation	Low ability to act – inequality and no institutions for sustainability and collaboration, no resources	Moderate ability to act – unequally distributed and no institutional conditions on social issues	Moderate ability to act – no institutional conditions for environmentally oriented action
	Quality of governance	High – focus on sustainability	Low and ineffective	High and effective	High – focus on businesses
Pathways	Agency capacities mobilised by pathways	All societal actors engage at multiple levels of governance: strong international collaboration and institutions for sustainability; European integration and multi-level, decentralised governance networks; support of market self-regulation, research and community action	Local community self-organisation and local, diversified economies acting within regional community networks for knowledge and resource exchange	Elite sets up a strong but flexible top-down master plan for European self-sufficiency, taking context-specific needs and opportunities into account, facilitating continuous monitoring and learning and directing resources towards green technological innovation	The private sector integrates environmental protection into business practice to ensure economic profitability in the long-term, invests in research, monitoring and green innovation and changes consumption practices

conjunction with pathway D) ambitious goals and showcasing how to achieve them in participatory and transparent ways and indirectly supports mainstreaming sustainable agriculture (pathway C) through strengthening environmental policy (pathway D). Analyses of interdependencies between pathways for the other context scenarios can be found in the Electronic Supplemental Material A.

As the pathways co-evolve over time, cross-sectoral interdependencies inevitably arise, resulting in trade-offs that must be recognised if the results are used for informing policy at the European level. Due to the central position of agriculture within the food-energy-water-environment nexus, trade-offs about land use (especially agriculture) occur in all scenarios. For example, there is a potential trade-off in SSP1 between agricultural expansion (arising from reducing imports to reduce food production externalities) and promoting nature protection and biodiversity. This trade-off could be avoided if sustainable intensification of agriculture delivers sufficient productivity gains. In the SSP3 scenario, there is a trade-off between setting land aside and incentivising forestry and nature-based solutions for flood management and increasing extensive grazing, given land availability constraints. Most of the other identified trade-offs are scenario-specific such as, for example, between higher taxes on water use in drier areas and universal access to water (SSP3) and between shifting towards integrated water management and improved irrigation efficiency that can counter-intuitively increase irrigation usage (SSP5).

Discussion

The outcomes of the participatory approach to pathway development to address high-end climate change have identified a nexus of three pathways that are robust to the future uncertainty across four contrasting scenarios that span a wide range of high-end climate and socioeconomic changes. The robust pathways include different types of climate change adaptation and mitigation strategies while also transforming European societies towards achieving the vision of a more sustainable future. Three highly interdependent pathways (lifestyles, governance and resource management) provide a policy-relevant framework to address the challenges of high-end futures. Compared to other pathways documented in the literature (Foxon 2013; Turnheim and Geels 2013), this study finds a robust pathway on shifts to sustainable lifestyles, which has been a previously underrepresented pathway. The policy implication from this pathway is that changes in lifestyles may influence both biodiversity goal achievement (addressed in European Union's Biodiversity Strategy) as well as pressure for sustainable agriculture practices that connect with a successful implementation and extension of the Common Agricultural Policy. It implies that cross-sectoral actions such

as lifestyle change require a cross-sectoral collaboration in policy and directive drafting at European level to ensure that policy externalities are minimised. The pathway of sustainable and integrated resource management provides insights and useful directions for the revision of the Common Agricultural Policy in terms of extending it in time and including new pillars to address bioeconomy, agroforestry and incentives for local sustainable agriculture initiatives as financial viable solutions to local economy. At the same time, the pathway of sustainable and integrated resource management shows how the Water Framework Directive can be implemented as a strategic design tool jointly with the Flood Directive of European Union while positioning nature-based solutions as valid actions for flood resilience.

The pathways developed in this study are consistent with the intended functions of pathways identified by Rosenbloom (2017). First, our pathways provide a useful bridging concept between scenario contexts, actions and a vision. The normative vision reflects values and aspirations for the future European society and stimulates the participants to think about actions to achieve equity, fairness, global leadership, high environmental quality and environmentally just economic progress.

Second, our pathways show possible future actions under a range of socioeconomic scenarios. This considers both the constraints and opportunities that different socioeconomic futures could provide, while also making sure that the actions are consistent with the scenario storyline and therefore more likely to be effective. These issues are critical for transformations towards sustainability. For example, if we find ourselves in an SSP3 world, actions that require strong governance are not feasible. The pathways instead show other possible future actions that could support the transformation to a more sustainable society. In contrast, an SSP1 world offers opportunities for strong regulations, while in an SSP5 world, investments in human and social capital are an opportunity. In an SSP4 world, the large gap between the elite and the rest of the population offers both opportunities (the elite can act efficiently) and constraints (potential social unrest). The cross-scenario comparison can be used to check the robustness of pathways, strategies and actions and thus show pathways that should work regardless of the socioeconomic future that evolves.

The pathways embody policy-relevant knowledge for addressing high-end climate change and supporting desirable societal transformations in the context of the different scenarios. For those pathways to further guide policy formulation at European, national or regional scales, we propose that the process we outline in this paper can be repeated with more stakeholders to further enrich the co-created pathways and to collaboratively operationalise them into action plans and policy proposals. Thus, these pathways can provide insights for formulation of new European directives and incentives for climate governance.

Third, our pathways include short-term actions (between 2017 and 2040) that create conditions for more daring actions in the medium- and long-term. Thus, the importance of the time dimension and the need for longer term strategic planning are demonstrated by the pathways. The assessment of synergies and trade-offs within and across pathways further elucidates the costs and investment effects of possible actions over time.

Fourth, our pathways have a learning function by showcasing patterns of interactions and feedback loops involved in social, economic and technological change. The interdependencies between the robust pathways and also the different strategies that are used in the different socioeconomic contexts demonstrate the complexity of climate governance. In addition, the pathways identify the multiple actors who can mobilise the resources, knowledge, skills and expertise needed for the implementation of actions and strategies.

Fifth, the co-production of actions by diverse stakeholders in our workshop process has led to pathways that include not only innovation but also destabilisation actions. Destabilisation can be the result of drastic changes in dismantling existing institutions (e.g. 'Removal of CAP subsidies' in pathway C.5, SSP5), changes of existing behaviours ('reducing water and food waste' in pathway A.1. in SSP1) and through changes of fossil-fuel use ('Introduce higher taxes for fossil fuels' in pathway E.5, SSP5). Destabilisation of institutions that no longer promote desirable social outcomes such as sustainability can be supported by lifestyle changes.

Conclusions

This paper has described the development and analysis of pathways for supporting Europe in moving towards a desirable future vision, through top-down and bottom-up adaptation, mitigation and transformational actions that reduce impacts and exploit opportunities associated with high-end climate and socioeconomic change. The pathways contain important (i) transformation strategies to move society towards more sustainable lifestyles and economies, (ii) mitigation strategies to transition Europe to a low-carbon economy and (iii) adaptation strategies to reduce the impacts and vulnerabilities associated with high-end climate change. Through the development of pathways within the context of four contrasting scenarios for the future of Europe, we have been able to identify pathways that are robust to inherently uncertain future social, economic and climatic conditions. In each of these scenarios, we find reflections of current developments in Europe. The pathways provide action directions with backing from both expert science and citizen science (due to continuous stakeholder involvement) for adaptation, mitigation and transformative action across sectors. However, it is unlikely that the pathways developed here are sufficient to enable

Europe to achieve the stakeholders' vision fully. This arises due to a combination of the significant residual impacts of high-end climate change, systemic time lags and/or recalcitrant characteristics of the socioeconomic scenarios.

The novel process that was developed and used to achieve these results built upon the inputs from a small but representative group of stakeholders and preparation and analysis by the research team. Our participatory application of an adapted transitions management approach has demonstrated how the co-development of pathways to achieve desirable normative vision under the irreducible uncertainty and complexity of high-end climate and socioeconomic futures can still meet the required functions of mapping, planning, learning, bridging and communicating (Rosenbloom 2017). It thus provides a valuable approach for supporting the multi-scale, multi-sector and multi-level policy responses required to address the challenges of meeting the Paris Agreement goals. However, further iterations of the process with broader representation of decision-maker, civil society and market actor groups will be necessary to reach a consensus on robust, innovative and effective solutions for addressing high-end climate and socioeconomic change. Such processes would result in learning about the complexity of risks and opportunities related to future developments, significant capacity building in the search for solutions and a broad agreement on a vision of the world that we want and what needs to be done to achieve it.

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Transition pathways to sustainability in greater than 2 C climate futures of Europe

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