Clarifying and strengthening the role of law and governance in climate scenario frameworks

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ABSTRACT

Shared socio-economic pathways (SSPs) and shared policy assumptions (SPAs) are lauded as a common basis for climate scenario research across disciplines, yet they lack essential legal and governance elements that are indispensable when assessing future development pathways. This article sets out to address this shortcoming by explaining the interrelated but distinct features of law and governance and their downplayed roles in climate scenario research. We explore the extent to which legal and governance features are included in the current SSP and SPA development process and then suggest that the substance of legal and governance features in climate scenario frameworks could be enriched in four ways, by: 1) identifying the nuances of legal and policy objectives; 2) assessing the effectiveness of institutions and instruments; 3) integrating the assessment of the flexibility and adaptability of legal and governance systems into the projection of long-term pathways; and 4) responding to the urgent need to integrate climate and energy justice while still cautiously considering normative principles to be opportunities and challenges. We further argue that future climate scenario frameworks should consider law and governance at multiple scales and in distinct contexts to improve the usability, applicability, and reliability of the integrated pathways. Finally, in order to project future risks, this article suggests improvement regarding the processes, including inter- and transdisciplinary inclusion that can potentially be considered when furthering climate scenario frameworks that enhance understanding of the complex, uncertain future and the long-term consequences of certain decisions.

1. Introduction

Scenario analysis is an important tool in climate change research and assessment to understand the long-term consequences of today's decisions and explore and evaluate uncertainties associated with possible future development pathways (Moss et al., 2010; van Vuuren et al., 2014; Riahi et al., 2017). More importantly, scenarios provide a common basis for exploring impacts, changes, solutions, and policies across different research communities (Moss et al., 2010; van Vuuren et al., 2014; O'Neill et al., 2014; Riahi et al., 2017). For this aim, in the past decade, a set of scenario frameworks has been gradually developed which combines the three pillars of (i) climate model projections, (ii) socio-economic development conditions, and (iii) assumptions about climate policies (Moss et al., 2010; Kriegler et al., 2012; van Vuuren et al., 2014).

The process of developing the scenario frameworks started some ten years ago with the first pillar, i.e., the Representative Concentration Pathways (RCPs), which describes different trajectories for radiative forcing related to greenhouse gas (GHG) emissions up until 2100 and their predicted associated concentration levels in 2100 (van Vuuren et al., 2011). The recently published 6th Assessment Report by the Intergovernmental Panel on Climate Change (IPCC AR6) (IPCC et al., 2021) assesses the climate response to five illustrative scenarios of RCPs: 1.9, 2.6, 4.5, 7.0, and 8.5 Watts/m^2 by 2100.

Applying RCPs alone, it is difficult to link the impacts of GHGs emissions to the worlds of economics, industrial activity, land use, and political interventions. As a result, the second pillar, shared socio-economic pathways (SSPs), has been developed to characterize alternative future worlds based on different development pathways and their associated challenges for climate mitigation and adaptation under

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baseline scenarios *without further climate policy* (O'Neill et al., 2014). O'Neill et al. (2017) defined SSPs as five qualitative, global descriptions/narratives of future changes in six elements: demographics; human development; economy and lifestyle; policies and institutions; technology; and environment and natural resources. In the IPCC AR6 (IPCC et al., 2021), SSP scenarios are applied to show how different *futures* could help or constrain the Paris Agreement target of controlling global average temperature rise well below 2 °C. RCPs and SSPs are complementary: RCPs indicate future emissions pathways while SSPs indicate the magnitude of challenges to climate change mitigation and adaptation in different baseline worlds with varying scenarios of socio-economic development, GHG emissions, and warming trends (IPCC et al., 2021).

The lesser known third pillar of the climate scenario framework is the Shared Climate Policy Assumptions (SPAs). Kriegler et al. (2014, p. 404) defined SPAs as "capturing *key characteristics of mitigation and adaptation policies* up to the global and century scale". SPAs were proposed to make climate analyses utilizing SSPs more flexible, i.e., allowing study of the impacts of different climate policies for a given pathway or the impacts of different SSPs on climate policies (Kriegler et al., 2012, 2014). The key distinction between SSPs and SPAs is that the former do not consider the impact of new climate policies on given pathways, and the latter only includes climate policies. Such a separation seems problematic, given the difficulty of drawing a clear boundary between climate and non-climate policies (Kriegler et al., 2014).

By observing the authorship of relevant publications and personally interacting with some of these authors, it became clear to us that the three concepts —RCP, SSP, and SPA—have been largely developed by the same community of climate modeling researchers (e.g., Van Vuuren et al., 2011; Kriegler et al., 2012; O'Neill et al., 2017; Riahi et al., 2017; O'Neill et al., 2020). The number of publications and their citations indicate that compared with SSPs, SPAs have been less developed and have had much less impact on climate research. Moreover, compared to the development of climate mitigation scenarios through the SPAs, the application of SPAs for developing *adaptation* scenarios is still limited, mainly because adaptation policies are highly context-specific, are spread across different policy sectors, and are typically generated at a regional level and co-produced with regional stakeholders (O'Neill et al., 2020).

It is noticeable that social scientists (with the exception of economists) have hardly been involved in either the substance (i.e., content) or the development of the current SSP and SPA frameworks (see also van Beek et al., 2020, 2022). Legal and governance scholars and practitioners are among those that have not contributed to developing, conducting, and promoting climate scenario research. We argue that it is essential to incorporate law and governance dimensions in the climate and socio-economic scenarios because these scenarios are used when making appropriate future policies to reach climate goals. In our view, the devising of scenarios is not inherently "neutral" but instead influenced by policy goals and processes behind it, that involve politics, and thus processes of law and policy making (van Beek et al., 2022; Muiderman et al., 2022). In parallel with physical boundary conditions, law and governance boundary conditions that encompass the dynamic of socio-political aspects would determine the feasibility of certain pathways and solution space (Du et al., 2022a; Rothman et al., 2014). Law and governance perspectives (e.g., normative principles, institutional frameworks, and regulatory regimes) are therefore essential in climate scenario frameworks for guiding a legitimate policymaking process and shaping better policies. Against this backdrop, this article reflects on the current status of legal and governance perspectives incorporated in the latest set of scenario frameworks used in IPCC AR6. To focus on the state of the art, we deliberately have not delved into the previous set of scenarios that were used in the previous assessment reports. In this article, we explore how legal and governance dimensions can be better included in the substance as well as in the process of developing such frameworks. We argue that including these perspectives will increase the potential of climate scenario frameworks to properly assess the consequences of decisions made today and to explore and evaluate uncertainties associated with possible future development pathways.

This article will proceed as follows. Section 2 provides the contextual basis, clarifying basic concepts related to law and governance and the methodology. Section 3 examines which legal and governance elements are already included in the current scenario frameworks. We elaborate on the current state of the art of SSP and SPA scholarship and substantiate how and where we see room to further strengthen the legal and governance dimensions. Section 4 provides insights into legal and governance features that can be better integrated into climate scenario frameworks. Section 4.1 addresses the substantiation of law and governance in climate scenario frameworks. Section 4.2 clarifies the usability and applicability of the identified substance of law and governance to multiple contexts and scales. It responds to the current call to extend the application of SSPs and SPAs to lower scales and broader sectors, especially for climate adaptation (O'Neill et al., 2020). Section 5 synthesizes the main findings, provides brief insights into ideal processes in developing future climate scenarios (i.e., steps toward interdisciplinary and transdisciplinary inclusions), and presents suggestions for future research.

2. Context and methodology

2.1. Law and governance as two additional dimensions of the climate scenario frameworks

First of all, law and governance are different subjects, though they do overlap. There are numerous definitions of law and governance.[1] Governance may be understood as a "*process* of more or less institutionalized interaction between public and/or private entities ultimately aiming to achieve collective goals" (Lange et al., 2013, p. 406). In most countries today, the law is *a body of rules or customs* recognized by a country or community for shaping social behaviors and enforced through its authorities (Morgan and Yeung, 2007). Law is one of many means of governance alongside others such as informal communications, collaborations, and negotiations. Likewise, governance manifests one function of law: the rules or customs for decision-making and policymaking. Law (in connection with sociology) can influence a governance process, and vice versa (Hunt and Wickham, 1994, p. 99). Law can be used to protect society against harmful decision-making processes. A group of persons can also use governance to propose and promote reform to adapt outdated laws to environmental and societal changes.

Second, some key terms used in interdisciplinary research have different connotations in legal and governance contexts. The academic disciplines of law and governance overlap greatly, as *substantively* they mostly research the same processes and issues, yet from a different perspective and with a different focus and methodologies. Understanding the distinction between key terms is necessary for interdisciplinary scholars to be able to formulate the narratives related to law and governance more precisely and avoid miscommunication. In the discourse on climate scenario frameworks, we observe the terms 'policy', 'law', and 'regulation' are used interchangeably. Policy "encompasses the content dimension of governance (in addition to the institutional structure (polity) and politics dimensions); it refers to policy formulation, implementation and monitoring and thus to objectives and instruments of *political* steering towards outputs" (Lange et al.,

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[1] One can hardly give a single definition of law because law has had different meanings at different periods over the centuries of evolvement, and different schools of law (e.g., natural law, positive law, legal ethics, and legal sociology) inherently perceive law differently. Similarly, there are different schools of thought for governance (traditional and modern governance), and disciplinary differences (political science, public administration, sustainability science, etc.).

2013, p. 411). In a legal context, the fundamental distinction between law and policy is that law is mainly for *bringing justice by its binding character* to society and therefore is more *stable and certain* (e. g. the 2019 Dutch Climate Act), whereas policy is intended to achieve certain goals whether or not they are enshrined in legislation (e. g. the 2019 Dutch National Energy and Climate Plan). Sometimes, a policy can (temporarily) fill the legal lacuna that arises when a legal instrument promulgated by the legislature is not available (e. g. Action Plan for Carbon Dioxide Peaking before 2030 in China, 2021), and some policies can eventually lead to new laws. Depending on the legal and political culture, a policy can sometimes play a role that is just as significant as that of legal instruments and have great stringency (e.g., policies issued by the communist parties in China and Vietnam). In the context of governance, regulation can be conceived as a "large subset of governance that is about steering the flow of events and behavior, as opposed to other two subsets of 'providing' and 'distributing''' (Braithwaite, et al., 2007). As a legal term, regulation has various levels of stringency in different contexts: EU regulations have a binding effect, while regulations in general can also be instruments softer than law (e.g. self-regulation).

Although legal and governance dimensions have distinct epistemologies, we argue that it is important to have common understanding of law and governance in our exploration to understand the extent to which legal and governance dimensions have been incorporated in the current SSPs and SPAs. Such common standing can be seen, for instance, in the context of national determined contributions (NDCs). The legal dimension of NDCs refers to the legal obligation on contracting parties to submit the highest possible and progressive mitigation commitments to the Paris Agreements, while the governance dimension of NDCs encompasses many factors including the policy framework and alignment of strategies and priorities to achieve climate goals, institutional arrangements, processes in decision making, capacity building, among others. We intend to contribute greater understanding mainly in terms of substance. For the purpose of this interdisciplinary paper, we define *substance* broadly as any legal and governance elements which have been or should be covered in the existing climate scenario assessment frameworks. We also briefly discuss ways to improve the *process* of integrating knowledge in scenario work and development of future climate scenarios, which includes the politics of inclusion in terms of who frames the future of climate policies, who implements the policies, and who becomes affected by the policies (see section 5).

2.2. Methodology

To examine how and to what extent legal and governance dimensions are incorporated in the current SSPs and SPAs, we used a mixed-method qualitative approach. We rely on the review of the published literature in order to outline the evolution of the concepts of SSPs and SPAs, which provide the fundament for our analysis of legal and governance elements. We supplement the literature review with observations from our participation in the Climate Scenario Forum on 20–22 June 2022 in Laxenburg, Austria, as well as in informal discussions with modelers working in the fields of SSPs and SPAs. We take an interdisciplinary approach based on our combined expertise in climate law and in governance and sustainable development.

Two points regarding the scope of this article are worth noting. First, this article will encompass SSPs and SPAs, but RCPs will be relevant insofar as RCP–SSP combinations are referred to in illustrations. Although multiple combinations of RCPs and SSPs are possible, five representative future scenarios are assessed in the IPCC AR6: SSP1-1.9; SSP1-2.6; SSP2-4.5; SSP3-7.0; and SSP5-8.5. Our reference to RCP–SSP combinations in this article conform with the IPCC AR6. Second, we have not separated non-climate policies and climate policies in our analysis but instead discuss them in an integrated manner insofar as they have direct or indirect relevance to climate mitigation and adaptation.

3. Incorporation of legal and governance features in the current SSPs and SPAs

3.1. SSP: its introduction to and further development and its positioning as a new scenario framework

The SSP concept was first introduced in the scholarly literature in 2012 (Kriegler et al., 2012). That study justified the importance of developing climate scenarios for defining policy options and research exploring how development pathways influence or are being influenced by climate futures. The introduction of the concept triggered more thinking on integrated assessment using narratives as well as quantitative projections. Key challenges were explained, from developing a truly integrated approach amid the complexity of climate change analysis to ensuring that the scenarios are plausible and compelling for policymakers. The study also introduced the concept of "shared policy assumptions", to augment the SSP concept in order to make climate policy analyses utilizing SSPs more flexible. In the paper, the governance dimension was present in some of the key challenges for using socio-economic scenarios for climate change, including the challenge of acknowledging the importance of local context through the interactions between essential parameters of climate vulnerabilities and responses. The governance dimension was shown under the socio-economic conditions parameter, i.e., technology and institutions, but no reference was cited. The word "policy" appeared frequently throughout the paper in relation to examples such as the robustness of global availability of climate impact insurance or of adaptation-related technology, and barriers to accessing adaptation technologies—for instance, due to regulation or lack of information. In addition, strong governance components were implied in an example of trends in development indicators across different scenarios that Kriegler et al. presented in their paper. The example—a scenario devised by The Energy and Resources Institute (TERI)— was one of the scenarios that inspired the development of SSP; its matrix included, *to some extent,* forms of modes of governance: state-led economic growth; a conservative approach with a focus on the environment; market-driven growth; and sustainable growth (Kriegler et al., 2012 p. 815). The aspect of collaboration was also framed as the aim of the SSP scenarios, to bring "integrated assessment and impact/adaptation/vulnerability researchers to assure coverage of key dimensions, sufficient scalability, and widespread adoption". In contrast to governance, law was not an independent dimension but instead was presented as "regulations" (e.g., on energy efficiency) embedded in climate or non-climate policies.

O'Neill et al. (2014) further developed the SSP concept by elaborating on the range of socio-economic challenges to mitigation and adaptation spanned by SSPs. The difficulties in adaptation are related to the function of the socio-economic determinants of *exposure to climate change hazards*, *sensitivity* to the hazards, and the *adaptive capacity* to cope with those hazards (O'Neill et al., 2014, pp. 392). These three challenges are all relevant to the governance dimension. Regarding adaptive capacity, three illustrative factors that influence this capacity were mentioned: 1) the availability of viable technological options for adaptation, 2) the effectiveness of relevant institutions (such as agricultural research and development, markets for goods affected by climate change, and forest management organizations), and 3) the availability of human and financial resources. The effectiveness of governance (point 2) significantly influences the shaping of policies and regulations that impact technology development, financial priorities, capacity building, and the allocation and utilization of resources. Governance-related elements were also found in two "possible elements of SSPs relevant to defining challenges to mitigation and adaptation" (O'Neill et al., 2014 pp. 396): the element of *institutions and governance* (which includes existence, type, and effectiveness of local-/national/regional/global institutions; and degree of participation), and the element of *broader societal factors* (which include attitudes to the environment, sustainability/worldviews/equity and societal tension

Table 1
SSP elements and benchmark (italic text indicates the elements directly linked to governance and legal dimensions).

Elements		Benchmark
Demographics	Population growth	Low/medium/high
	Fertility	
	Mortality	
	Migration	
	Urbanization level and type	Low/medium/high and level of management
Human development	Education	Low/medium/high and level of management
	Health Investments	
	Access to health facilities, water, sanitation	
	Gender equality	
	Equity	
	Social cohesion	
	Societal participation	
Economy and lifestyle	Growth per capita	low/medium/high
	Inequality	Reduced/high/uneven
	International trade	Moderate/strongly constrained/high
	Globalization	Connected/semi-open/deglobalizing/type of network and sector connected
	Consumption and diet	Low/high/intensive material consumption and meat consumption
Policies and institutions	*International cooperation*	Effectiveness/weakness
	Environmental policy	Priority for local or global environmental issues/implementation of the regulation of pollutants
	Policy orientation	Focus on certain long-/short-term objectives (sustainability/political benefits)
	Institution	Effectiveness/inclusions
Technology	Development	Slow/medium/rapid/even or uneven
	Transfer	
	Energy technology change	Toward renewable energy and ending reliance on fossil fuels
	Carbon intensity	Low/medium/high
	Energy intensity	Low/medium/high/even or uneven
Environment and natural resources	Fossil constraints	References shift away from fossil fuel/No reluctance to use unconventional resources/Unconventional resources for domestic supply/Anticipation of constraints drives up prices with high volatility
	Environment	Management improvement and degradation level
	Land use	Availability of regulations and level (strong/medium/no regulation) for deforestation
	Agriculture	Productivity/best practices/level of technological change/scale of farming

Source: Adapted from O'Neill et al. (2017).

and conflict level). However, no further elaboration seems to be available on the meaning of each element and how these narratives could meaningfully contribute to the SSP projections. Regarding the legal dimension, the "rule of law" was mentioned under the element of "institutions and governance", and the term "policies" was still used to a large extent with reference to laws and regulations regardless of the differences in the terminology of law, regulation, and policy (e.g., energy, urban planning, environmental protection) (see Table 1 in O'Neill et al. (2014) p. 396).

3.2. The shared climate policy assumptions (SPAs) and the development of the detailed set of assumptions

Concomitantly with the development of RCPs and SSPs, the scenario development communities realized the need to augment SSPs with SPAs. The definition of SPAs is based on three attributes (Kriegler et al., 2014): 1) Global collection of climate policy goals, 2) Characteristics of the global collection of policy and measures introduced to reach the policy goals, and 3) Implementation limits and obstacles to the extent they are considered and are not part of an SSP. Policy regimes and measures that support adaptation include, e.g., technology transfer mechanisms (Kriegler et al., 2012, p. 813). In addition, the *quality* of the adaptation governance process was mentioned by outlining the problem of corruption and vested interests. Furthermore, the *effectiveness* of policy implementation for climate adaptation was also touched upon; for example, in relation to the enforcement of creating norms and land-use regulations. Finally, the Kriegler et al. (2014) study presented a selection of illustrative global policy attributes for SPA narratives related to adaptation, such as capacity building (the size of a global adaptation fund) and international insurance (availability of climate impact insurance in different countries). Once again, there is an implicit legal dimension in the SPA framework: the broader concept of "policy regimes and measures".

Two papers published in 2017 presented adaptation and mitigation challenges, a revised set of SSP assumptions, and global SSP1 to 5 narratives (see O'Neill et al., 2017; Riahi et al., 2017). They projected five qualitative descriptions of possible futures: SSP1 for sustainability; SSP2 for a middle way not markedly shifted from historical patterns; SSP3 for a weakest pathway with highest challenges to mitigation and adaptation; SSP4 for an unequal future between countries; and SSP5 for a highly engineered, technical and high-emission future. The five narratives encompass key elements in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources. All elements are, to some extent relevant to law and governance, as the status of each development trajectory and narratives always relates to the characterization and effectiveness of institutions and their feedback mechanisms (e.g., good governance and rule of law increase education and gross domestic product and vice versa) (see also Andrijevic et al., 2020). The governance and legal aspects were covered in several assumptions that were simpler than those presented earlier by Kriegler et al. (2012). There are four main elements we consider directly relevant to law and governance: *human development*, which includes the sub-elements of social cohesion and societal participation; *economy and lifestyle,* in particular regarding the *policies and institutions*, including sub-elements of international cooperation, environmental policy, policy orientation, and effectiveness of institutions; and *environment and natural resources*, which include the regulations on land use and air pollution (O'Neill et al., 2017, pp. 176–177).

3.3. Recent synthesis of the scenario framework

In the latest paper by O'Neill et al. (2020), some synthesized reflections were given on the evolution of climate scenario development, its usefulness, and challenges for the future in light of the dynamic changes in climate forcing, socio-economic, and policy contexts. One

reflection that is particularly relevant to the governance and legal dimensions is that the current SSPs have purposely been designed as a *global narrative*, whereas an extended SSP framework that entails applying basic SSPs in different contexts (sectoral, regional, and local) will make SSPs more useful for decision-makers at those sectors or levels (see also O'Neill et al., 2014). This reflection is consistent with the features of law and governance, which are largely context-specific (this will be further addressed in section 4.2). Another reflection relates to the difficulty of separating SSP (non-climate policy assumptions) from SPA (climate policy assumptions) in the context of sustainable development research. For example, it is questionable whether a climate-related policy with multiple objectives (e.g., a land-use policy that has an impact on climate adaptation, or a policy for controlling air pollution that has spin-offs on emissions reduction) should be included in SSPs or SPAs (Kriegler et al., 2014, Bulkeley, 2021). If the RCP–SSP framework is extended to sustainable development research, the distinction between SSPs and SPAs will become less valuable, and "there is a need to identify SSP-SPA combinations that are tailored to the analysis of sustainable development policies" (O'Neill et al., 2020, p. 1080). As already stated in section 2.2, we have accepted the challenge in this reflection and will address both SPA and SSP together below in terms of their content by addressing both policies together throughout the content below.

3.4. Observations and reflections

Based on the key literature above, we observe that there has been limited incorporation of governance and legal dimensions either because of oversimplification (which became even greater over time from Kriegler et al., 2012 to O'Neill et al., 2017) of some legal and governance factors, the absence of feedback loop narratives, or the omission of some crucial features of law and governance. Although the current SSPs have included some governance and legal elements (see O'Neill et al., 2017 and Table 1 below), those elements do not adequately cover climate governance and law but are rather illustrative factors. For instance, although there is some description of substantive rules in the current SSP assumptions about the stringency of regulations on land-use change and deforestation and environmental policies regulating pollution (Table 1 below), challenges remained when those assumptions failed to incorporate the complex sub-factors that collectively influence the stringency of regulatory instruments (Oberthür, 2019). Similarly, the current manner of integrating the broad factor of the "rule of law" seems too broad (O'Neill et al., 2014, Table 1). Among others, the degree of implementation and enforcement of law needs to be unpacked in the assumptions regarding policy stringency and rule of law (see further discussion in section 4.1.2).

Moreover, normative aspects are still underexplored (although equity, gender equality, etc. are available in the SSPs; see Table 1 below). Based on our own observations, this shortcoming is partly due to the controversy about selecting the "right" normative principles (e.g., democracy) and the completeness of incorporating the abstract normativity into assessments (e.g., justice). In section 4, we elaborate on why these features should be better incorporated into climate scenario frameworks and how this can be done.

4. Strengthening the integration of law and governance into climate scenario frameworks

To counter the findings presented in section 3, in this section, we propose to enrich the substance of law and governance for a more comprehensive climate scenario framework and to enable the enriched substance to be made applicable in multiple contexts and at multiple scales. Specific content might differ not only at the global and international levels, but also based on the national, regional, and local contexts.

4.1. Enriching the substance of law and governance

The key aspects with which we propose to enrich the substance of law and governance in the climate scenario frameworks are 1) legal and policy objectives, 2) the effectiveness of institutions and instruments, 3) the flexibility and adaptability of legal and governance systems, and 4) the normativity of law and governance. The consideration of these aspects will also contribute to evaluating the (un)certainties of legal and governance systems associated with the assessments of long-term socio-economic pathways.

4.1.1. Legal and policy objectives

Whereas policy planning is often a five- or six-year cycle, legal objectives are mostly established for a relatively long term and therefore enjoy a greater degree of stability and certainty. The most traditional purposes of law can be the realization of democracy and justice; legal objectives can also respond to the societal call for sustainable development goals and economic objectives. Objectives are formulated variously in specific regulatory instruments. In SSP assumptions, environmental concerns in socio-economic development strategies and plans (in SSP1- sustainable pathway) or the belief in putting capital and welfare first (in SSP5- high-tech pathway) can be mainstreamed into legal instruments. In both pathways, the establishment of legal objectives can catalyze the achievement of policy goals (either "sustainability" or "economy first") because these goals become legally binding and mandatory, and the consequence of non-compliance (e.g., economic sanctions) will apply so that the legal obligations can be enforced. For instance, the new European Climate Law developed as a part of the European Green Deal recognizes the policy goal of "climate neutrality by 2050" as a legally binding objective (European Commission, 2019; European Parliament and Council, 2021). Such legalization of a policy goal increases the certainty of this goal at least until 2050 in terms of encouraging actions tackling climate change and pursuing sustainability (Du and Zhang, 2022). This legal objective also implies that SSP1 resembles the pathway in line with the EU climate law regime. Integrated assessment modelers already noticed the relevance of legal bindingness of regulatory instruments for the assessment of the credibility of net-zero commitments (Rogelj et al., 2023). Note that the objective needs to be backed by other instruments and mechanisms (e.g., the Carbon Border Adjustment Mechanism) to prevent climate neutrality being arrived at by transferring emissions and damage to outside the EU, because otherwise, a pure climate goal that does not take due account of transboundary equality and justice would actually result in SSPs 3 or 4 (the normativity issues will be further discussed in section 4.1.4).

From the viewpoint of governance, the process of developing policy goals is a complex and intricate issue, as it deals with diverse interests of actors and institutions, making policy goals development both highly political and uncertain in the process (Bulkeley and Betsill, 2005; Hale and Roger, 2014). The process includes problem framing and prioritization of policy goals. These goals are considered an inherently political process and relate to the difficult questions of who gets to decide the policy goals, and what role institutions play in the whole goal-framing process. The uncertainties here refer both to external changes (extreme events and shocks) and internal changes in the governance system (as in the case of radical exercise of power and societal movements). While policy goals can be established in predictable timeframes and somewhat reduce the level of uncertainty (e.g., following a medium-to long-term policy cycle), realizing these goals is more of a challenge (Bulkeley and Betsill, 2005; May and Jochim, 2013). We cannot simply assume that a policy that has been adopted will be implemented without problems, as implementation is accompanied by societal, technical, financial, institutional, and legal challenges. Moreover, actors in the implementation process may challenge the existing policy and became an important barrier for effective implementation (Triyanti et al., 2020; Biesbroek et al., 2014). A case in point when it comes to governance approaches needed in relation to different levels of

stability is water management in the Netherlands. Here, stability is present in the ongoing focus on flood defense (i.e., a persistent long-term goal), but meanwhile, the less stable factor relates to the multi-level characteristics of flood risk governance, which require different and dynamic governance approaches or modes (e.g., to become more participatory/include new actors) (Hegger et al., 2020).

4.1.2. The effectiveness of institutions and regulatory instruments

The effectiveness of institutions and instruments is relevant for both the legal and governance dimensions of integrated scenarios. Two key criteria for the assessment of effectiveness are 1) the organization and functioning of institutions and 2) the implementation and enforcement of binding legal and policy instruments. From a legal perspective, the former refers to the administrative rules regarding the designation of responsibilities to actors and the division of responsibilities. In SSP assumptions, institutional aspects are already available under the element of "policies and institutions", which focus on the assessment of "effectiveness" (O'Neill et al., 2017). For a sufficient assessment, assumptions should be based primarily on the administrative environmental rules and procedures in domestic or international environmental legal regulations. The legal assumptions of "effectiveness" should primarily focus on the quality of communication, coordination, and collaboration between actors and institutions within or beyond one country (Faure, 2011; Gilissen et al., 2021). The legal assumptions of the institutional aspect can also be extended to the appropriateness, i.e., the suitability and competence of actors in fulfilling specific responsibilities. The abovementioned indicators for the effectiveness of institutions could not only improve the completeness of the projections of climate scenarios and pathways but also indicate the constraints which must be removed to achieve a sustainable transformation.

Institutions in the governance systems are deemed effective if they succeed in achieving goals by applying good governance strategies. Governance can be said to be good or effective if it meets a set of criteria that assesses, among other things, participation, the rule of law, transparency, responsiveness, consensus-oriented, equity and inclusiveness, effectiveness and efficiency, and accountability (UNESCAP, 2009). These are primarily normative values, which are difficult to measure with constant control variables. Moving away from this concept, effective governance manifests in effective interactions, coordination between actors, instruments, and effective modes of governance in general (e.g., top-down, bottom-up, or hybrid network governance: see also Hickmann et al., 2022) For example, in the case of ecosystem-based adaptation, effective governance entails a combination of bottom-up and hybrid governance that promotes close interactions between actors, especially local governments and communities closer to the measures being taken; these elements will enhance the success of implementing strategies to achieve the policy goals (Triyanti et al., 2017).

Poor implementation and enforcement of regulatory instruments are common problems that impede the effectiveness of law in almost all jurisdictions. The various capabilities of implementation and enforcement impact the certainty of achieving the established goals and therefore make the impacts of the law on future development less certain. The reasons are various and complex. One reason is that some legal obligations are not well designed and will cause the implementation to deviate from the original goal. For instance, in the Vietnamese Mekong Delta there are loopholes in the current regulations on balancing the expansion of shrimp production and mangrove deforestation in the coastal area. In Ca Mau province, a combination of mangrove–shrimp farming is permitted (Ha et al., 2012), but the rule of keeping a minimum of 60 percent of land plots under mangroves is implemented without good faith (a sincere intention to be fair and honest). Planting mangroves in remote areas to compensate for the coastal area occupied by shrimp ponds is sham compliance and does not restore the coastal ecosystem (Du et al., 2022b). More complex reasons relate to the legal, political, and cultural national or regional context,

which leads to distinctive ways of implementation and enforcement influencing the effectiveness of policies; each national system has its own opportunities and pitfalls. Consider the example of the policy-making process of "sponge city" (a metaphor for integrated water management in urban areas, making the city a "sponge" to provide and absorb water where needed) in China (Dai et al., 2018). Thanks to the hierarchical system in China, the national goal of climate adaptation in urban areas can be quickly and efficiently broken down into municipal targets, and the assessment of targets can be linked to the performance of individual cadres. To a certain extent, such a system *increases the certainty* of realizing a legal or policy goal, as long as the Chinese Communist Party adopts that goal and aims to achieve it. However, there remains a risk of non-compliance or insufficient compliance where discrepant practices arise in different municipalities and subsequently lead to total or partial failure to achieve the goal of urban flood prevention. This, in turn, *decreases the certainty* of the future implementation and enforcement of the law. Further, absence of regulatory instruments for certain mitigation actions may make some scenarios unrealistic. For example, if the information regarding the availability of domestic regulations or bilateral agreements on carbon capture and storage is incorporated into SSPs, some ambitious mitigation scenarios which highly rely on CCS would become impossible.

The fragmentation of agencies and policies becomes a significant implementation challenge from a governance and legal perspective. For example, in climate adaptation, the tasks and responsibilities of the agencies involved often overlap. In addition, when stakeholders discuss the monitoring, the lack of knowledge and data on the current status of progress in climate policies make the likelihood of implementation and the accuracy of the monitoring less predictable. An example at the national level would be the NDCs and national adaptation plans (NAPs) as mechanisms for countries to report on their progress in achieving the Paris Agreement. A major issue surrounding the current NDCs and NAPs is the inadequacy of available data and capacity such as conducting climate scenario analysis (Triyanti et al., 2021). Additionally, there is the issue of contentious political exercise wherein the reporting mechanism, including climate scenario development, is used to legitimize existing policy (Jernnäs et al., 2019; Rivadeneira and Carton, 2022). Rather than conducting a thorough and genuine evaluation of the policies currently in place, this practice could result in presenting a biased or overly positive view on these policies through the reporting process (see also Jernnäs et al., 2019).

4.1.3. The flexibility and adaptability of a legal and governance system

A legal system contains all binding and non-binding rules and norms in an operating unit with definite boundaries, most commonly the boundary of a sovereignty (Friedman, 1975, pp. 5–6). Meanwhile, a governance system means a total set of mechanisms and processes that are available for guidance, control and steerage (Chuenpagdee and Jentoft, 2013, pp. 16). A governance system includes actors, entities, and parties that have the capacity for governing tasks (Kooiman, 2008, p. 2). The flexibility and adaptability of a legal and governance system are relevant for the scenario mapping of socio-economic trends because such features influence the extent to which legal and governance systems can support the continuous pursuit of established long-term goals in spite of societal disturbances and unforeseen crises.

The flexibility of law emphasizes the ability of a legal system to respond timely to socio-economic and/or environmental changes (Du et al., 2022a). For instance, there are differences between the civil law system and the common law system. Moreover, it is relevant whether a jurisdiction has a culture of strict compliance or allows greater discretion (room for interpretation). The adaptiveness of law will impact long-term assumptions of socio-economic development, e.g., those relating to the year 2100. A wide range of literature has already developed various facets of the adaptiveness of law (Humby, 2014a, b). The standard criteria for assessing the adaptiveness of law include *planning and setting goals and tasks, periodic review, and adjustment*

(Garmestani et al., 2013), applying an *experimental approach* when making regulations and policies (Termeer et al., 2011; Heldeweg, 2017), and *broad participation* to facilitate learning from societal disturbances (Wenta et al., 2019). These criteria could perhaps be quantified and would then become useful complements to the climate scenario frameworks for a more detailed exploration of the flexibility and adaptiveness of law and its implications for long-term scenarios and pathways.

The resilience of a socio-ecological system greatly depends on the adaptiveness of the systems through which it is governed (see Hegger et al., 2016). A core strategy to increase adaptiveness entails increasing institutional multiplicity and redundancy. This means setting up redundant resources and capacity, looking beyond predicted changes, and anticipating failure scenarios (Bahadur et al., 2013). An example is the development of bottom-up initiatives such as multi-stakeholder platforms which allow actors to flexibly change their roles as they see appropriate (Huntjens et al., 2012). This will provide a space for triple-loop learning, and room to nourish leadership, while it is important to still adhere to the principle of fair governance (Gupta et al., 2016). However, these processes are truly dynamic and not easy to trace and assess, and how these strategies are implemented will vary, depending on the context. Redundancies, are still seen as inefficiencies, however: for example, because overlapping institutions and tasks imply increased costs. This is especially true when performance is seen as short-term output rather than as long-term capacity development to deal with uncertainty (Low et al., 2003; Herrfahrdt-Pähle, 2013).

4.1.4. Normativity as opportunities and challenges

Normative aspects can be found in the SSP elements of "gender equality" and "equity" under "human development", and "inequality" under "economy and lifestyle" (see Table 1 in section 3.4). In this section, we argue for the more explicit and comprehensive integration of normative principles, *inter alia* the normative elements that safeguard *climate and energy justice*, into climate scenario frameworks.

Although the concepts of climate justice and energy justice have been developed from the literature on environmental justice (Schlosberg, 2007, Chapter 2), climate justice strives to achieve climate neutrality and resilience without undermining human rights, including the right to development (Robinson and Shine, 2018), while energy justice essentially seeks to make energy systems equitable and non-discriminatory (Walker, 2009; McCauley et al., 2013). Among the key tenets of climate and energy justice are the fair *distribution* of impacts, costs, and benefits, the *recognition* of vulnerabilities, and the process of inclusive *participation* (Schlosberg and Collins, 2014; McCauley et al., 2013). Take SSP1 (sustainable pathway) as an example. Ideally, sustainability shall be achieved by balancing environmental, societal, and economic interests (Bosselmann, 2016). Under RCP1.9-SSP1 (best scenario toward sustainability), the achievement of ambitious environmental targets might come at the price of imbalance between interests and implies that the vulnerable will disproportionately bear the costs.

Mitigation scenarios simulated by using Integrated Assessment Models have not so far intentionally considered justice (Rivadeneira and Carton, 2022). But given the justice implications of climate assumptions and modeling and their influence in policy decisions, a more explicit consideration of justice in climate scenario frameworks is necessary (Rivadeneira and Carton, 2022). One possible way to integrate the justice dimension into climate scenario frameworks would be to assess the institutional and regulatory frameworks that deal with concerns about distribution, recognition, and participation in climate and energy transition.

Regarding the integration of justice into adaptation scenarios, an example is to consider—as explicitly and early as possible— integrating and assessing loss and damage (L&D). Relevant legal elements include the polluter pays principle and environmental liability applied in climate-related disasters (see also Driessen and van Rijswick, 2011; Scown et al., 2022). L&D was included as one of the main items on the COP (Conference of the Parties) agenda for the first time in 2022 at COP 27 in Sharm El-Sheikh, Egypt. The resolution to establish a loss and damage fund (UNFCCC, 2022) shows high consideration of *distributive* and *recognition* justice, with developed countries acknowledging their accountability for large emissions of GHG in the past and agreeing to provide developing countries—who are affected the most from climate change impacts—with financial compensation. However, the quality of *participatory* justice remains a challenge, as the procedures and mechanisms for achieving procedures and implementation are still yet to be established.

Along these lines, it is also vital to discuss equality in the context of just transformation. The notion of transformation has its own pitfalls and risks, especially the risk of reinforcing systemic injustice and political dilemmas (e.g., as experienced by developing nations) which hinder the progress of transformation (Blythe et al., 2018). Cases in point are climate colonialism and the shift of climate mitigation and adaptation responsibilities from the Global North to the Global South (Mahony and Endfield, 2018; Hickel, 2020).

In contrast to the widely recognized values of justice, one should be cautious when incorporating elements such as "democracy" in socio-political contexts across nations (bearing in mind that "democracy" was discussed in one plenary session of the Climate Scenario Forum, 2022). In the past decade, contestation has arisen around democracy's limitations when tackling climate change (Povitkina, 2018), the unacceptance of this Western-derived concept in alternative socio-political contexts (Spiess, 2008), and the conspicuous achievements of climate mitigation in East Asia, especially China (Gilley, 2012; Beeson, 2018).

4.2. Law and governance in multiple contexts and scales: usability and applicability

After explaining the substance of law and governance relevant to climate scenario frameworks, it is also important to examine its usability and its applicability to multiple contexts and scales, especially because of the call to extend SSPs to lower scales and different sectors (O'Neill et al., 2014; O'Neill et al., 2020). Such an examination should focus not only on paying attention to scale specificity, but also on the interaction between multi-scale approaches and multi-level governance.

The legal and governance dimensions of extended pathways for climate mitigation at lower scales largely manifest as emissions reduction, carbon sinks, and renewable energy targets, together with the corresponding implementation and enforcement mechanisms (if any) established by the national governments and then distributed to subnational regions and economic sectors. The uncertainty of implementation and enforcement and the adaptability of a legal and governance system to absorb disturbance (e.g., an energy crisis) (as stated in Sections 4.1.2 and 4.1.3) would typically influence the extended pathways across contexts and scales.

Compared with mitigation, climate adaptation faces greater challenges of downscaling in climate scenario research. This is due to the context- and scale-specificness of the strategies (O'Neill et al., 2020). Climate adaptation requires addressing the challenges of "meeting basic needs and everyday survival" (Bulkeley et al., 2011, p. 129) when dealing with climate change impacts, especially at the local level. Adaptation options are wide-ranging and include structural adaptation (e.g., resilient infrastructure) and social (e.g., awareness raising) and institutional (e.g., law and policies) strategies (see Noble et al., 2014, p. 845). This high diversity of climate adaptation strategies makes monitoring more difficult. There has been quantitative research on defining the regional and national scenarios and pathways (e.g., Palazzo et al., 2017; Kok et al., 2019; Lehtonen et al., 2021), but there is still room for combining such research with qualitative context-specific assessments of future governance change to the existing quantitative governance scenario done by Andrijevic et al. (2020). From a legal and governance perspective, the context- and scale-specificity of climate adaptation ranges from international, national, sub-national, and provincial to

municipal levels, taking into account institutions, regulatory instruments, and actors in different jurisdictions, and local customs that indigenous people and communities abide by and that are recognized as "soft law". One of the main challenges of incorporating the substantive regulations and policies for climate adaptation into assessment modeling is that climate adaptation is mostly spin-offs of regulations and policies related to land use, water management, environmental protection, natural resources and ecosystem conservation, infrastructure building and maintenance, technological innovation and transfer, and urban planning, rather than regulations and policies explicitly addressing climate adaptation.

The more compelling concern relating to adaptation is that even if climate scientists are aware of the difficulty of incorporating the context- and scale-specificity of different legal and governance systems, it remains unclear how law and governance can nevertheless contribute to the policies assumptions at global level. In other words, to what extent are we still able to properly develop climate adaptation assumptions in a global context? The UN climate regime provides an example. Global climate adaptation can be found in Article 7 of the Paris Agreement in the form of setting the global goals for adaptation: enhancing adaptive capacity and resilience; reducing vulnerability, with a view to contributing to sustainable development; and ensuring an adequate adaptation response in the context of the goal of limiting temperature rise to 2 °C or 1.5 °C. These three elements can be included across climate adaptation assumptions.

5. Conclusion and research agenda

This paper has focused on the underexplored legal and governance contributions to the current development of climate scenario frameworks, as the current frameworks focus strongly on the incorporation of natural science and economics. We have clarified the understanding of the legal and governance dimensions as a research context and provided an overview of existing legal and governance elements within the SSPs and SPAs. Based on our analysis of the substance of law and governance, we came up with four aspects of strengthening the integration of legal and governance elements in climate scenario development, especially when dealing with uncertainties: 1) identifying the nuances of legal and policy objectives; 2) assessing the effectiveness of institutions and the implementation and enforcement of regulatory instruments; 3) integrating the assessment of the flexibility and adaptability of legal and governance systems into the projection of long-term pathways; and 4) responding to the urgent need to integrate climate and energy justice by cautiously considering different normative principles as opportunities and challenges. The added value of incorporating those substantive elements is that they would complement scenario inputs so as to improve the reliability and comprehensiveness of scenario outcomes.

We also discussed the usability and applicability of these elements in multiple contexts and at various scales. An elaboration on the substance of law and governance as stated in section 4.1 would provide modelers with information to enable them to better understand and deal with uncertainties associated with the features of law and governance of a region. Although the main goal is to develop a global template for climate scenario research, the climate scenario research community should iteratively reflect on the applicability and plausibility of the climate scenarios in terms of units at different scales (regional, national, and local levels). In practice, the improved process means:

1) taking stock of existing global, international, regional, national, and sub-national policies in terms of their consideration of normative principles to guide the selection of climate policies in the climate scenario framework. Any normative addition to SSPs and SPAs, especially values that are controversial, should be subjected to inclusive and deliberative discussion before being integrated into the narratives and modeling; and

2) developing methods to downscale the climate scenario development to regional, national, and sub-national level. It is currently not clear to what extent downscaling is possible (e.g., due to methodological or technical limitations and the role of law and governance therein).

Regarding some specific future research, undertaking empirical studies by interviewing experts on the necessity and feasibility of integrating the four proposed substantive elements in section 4.1 would verify our present desk-based analysis. Such empirical research would pave the way for investigating to what extent the proposed legal and governance aspects are quantifiable and thus can be incorporated into various integrated assessment models. Among the four substantive elements, one prominent contribution of law and governance is to help develop the methods for assessing how different capacities of implementing and enforcing laws and policies would bring different outcomes in different scenarios. Furthermore, a reliable assessment cannot be achieved without examining the implementation of laws and policies at lower scales. Enabling assessing implementation at multiple scales will promisingly fill in a gap in current integrated scenarios and pathways. An example is whether mitigation actions such as carbon capture and storage are legally (as well as technically) feasible in different regions.

As Weyant (2017) put it: "While the models can be improved in many areas, much of the uncertainty that exists reflects a lack of complete scientific understanding of the systems involved rather than limitations of one or another approach to model construction and use." The emerging requirement is to integrate not only "physical and economic system understanding" (Weyant, 2017), but also the features of legal and governance systems. This leads to our reflections on reevaluating the process aspects of climate scenario development. Climate scenario development communities should expand the knowledge base, which is still dominated by natural science and economics, by engaging different knowledge systems. The first step could be to strengthen the disciplinary base within the climate scenario and research communities by including legal and governance scholars in their future development of integrated assessment frameworks. Although this process could result in complexity emerging upfront, it is still worthwhile doing to avoid the risk of ineffective and even inappropriate uses of the scenarios in research and decision-making. In addition, climate scientists need to forge stronger connections with legal, policy, and governance scholars for more disciplinary expertise to improve the robustness of the assessment of certain factors, e.g., rule of law and policy implementation. Meanwhile those scholars also require climate scientists to provide future-proof scientific evidence for making climate law and policy adaptive as well as moving forward with climate litigation.

CRediT authorship contribution statement

Annisa Triyanti: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Haomiao Du:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Dries L.T. Hegger:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Peter P.J. Driessen:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Helena F.M.W. van Rijswick:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Murray Scown:** Formal analysis, Methodology, Writing – review & editing. **Herman Kasper Gilissen:** Conceptualization, Methodology, Writing – review & editing.

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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