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Enriching the concept of solution space for climate adaptation by unfolding legal and governance dimensions

Haomiao Du [a], Annisa Triyanti [b,*], Dries L.T. Hegger [b], Herman Kasper Gilissen [a], Peter P. J. Driessen [b], Helena F.M.W. van Rijswick [a]

[a] Utrecht Centre for Water, Oceans and Sustainability Law, Utrecht University, Utrecht, The Netherlands
[b] Environmental Governance, Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, The Netherlands

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ABSTRACT

Conspicuous interdisciplinary effort has been spent on addressing the consequences of climate change in a forward-looking way. The concept of solution space is a recent contribution to help decision-makers identify feasible and effective adaptation solutions and to provide guidance on when they should be implemented and by whom. Although the current conceptualization of solution space already considers multiple disciplines, it remains dominated by biophysical ones and has not yet fully integrated legal and governance dimensions. This article first reflects on the current solution space framework through the lenses of law and governance and then proposes approaches to enrich legal and governance dimensions in the solution space concept. We argue that the legal and governance dimensions of the current concept of solution space can be improved by taking into account four aspects: 1) understanding the institutional and legal systems in a context-specific way; 2) embracing the dynamics and reflexivity of law and governance in the episteme of path dependency; 3) applying more diverse analytical methods (qualitative, qualitative/ quantitative, value-oriented) and/or assessments on a case-by-case basis; and 4) adding a normative perspective that includes the principles of legitimacy, transparency, accountability, equity, and distributive justice to measure the appropriateness of a certain adaptation strategy. The article concludes with suggestions for future research on how to implement the enriched solution space concept.

1. Introduction

Scientists from a range of disciplines have acknowledged the importance of undertaking interdisciplinary and transdisciplinary research, especially when natural and social scientists are attempting to gain a shared understanding of a problem and its solutions (Bodin, 2017; Castree et al., 2014; Lach, 2014). A recent response to such a challenge has been the development of the concept of solution space in the domain of climate change adaptation.

Developing, selecting, and implementing adaptation solutions is daunting, due to the interactions between the physical and social systems. On the one hand, uncertainty about the impact of climate change on the physical system, such as the accelerating rate of global temperature and sea-level rise and the increasing frequency and severity of extreme weather events, makes it challenging for decision-makers to define appropriate adaptation strategies. On the other hand, uncertainty also exists within social systems: for instance, about the behaviour of organizations and people, macro-economic developments, and political dynamics (see Raadgever et al., 2011).

The successful and unsuccessful adaptation actions observed in the past decade demonstrate the importance of understanding the boundary conditions that determine the solution space for climate change adaptation and the ways to influence this space (Haasnoot et al., 2020).[1] To accelerate adaptation action, it is critical to provide policymakers with a full picture of boundary conditions for identifying feasible, effective, affordable, and appropriate climate adaptation action. In the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, an early model of the solution space framework was presented for assessing climate adaptation and vulnerability (Sainz de Murieta et al., 2014). More recently, building on earlier studies on thresholds, limits,

* Correspondence to: Environmental Governance, Copernicus Institute of Sustainable Development, Utrecht University, P. O. Box 80.115, 3584 CB Utrecht, The Netherlands.
E-mail address: a.triyanti@uu.nl (A. Triyanti).

[1] Boundary conditions are the conditions that must be satisfied to define solution space for climate adaptation. Haasnoot et al. (2020: Table 1) identified two main categories of boundary conditions:, biophysical and societal.

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and barriers to adaptation (Dow et al., 2013), policy pathways (Haasnoot et al., 2013), (mal)adaptive space[2] (Wise et al., 2014), and Shared Socio-Economic Pathways[3] (O'Neill et al., 2017), Haasnoot et al. (2020) have conceptualized 'solution space' as a changing space which indicates possible adaptation options, changes, and shocks – as well as alternative pathways over time and across contexts.

Although the current conceptualization of solution space for climate adaptation already includes the political–institutional dimension in the 'scope of crafting solutions' (Haasnoot et al., 2020: Table 1), its legal and governance dimensions have not yet been fully unpacked and elaborated. It is relevant to do so, given that law and governance are complex, case- and context-specific, dynamic, and unquantifiable. Legal and governance dimensions are especially important in the solution space concept for (a) defining the problem in climate adaptation and identifying the boundary conditions; and (b) evaluating whether certain adaptation solutions can be effectively implemented, monitored, and sustained on the ground by the governing actors, including public authorities, non-governmental organizations, and civil society.

This article aims to enrich the concept of solution space by unfolding its legal and governance dimensions. Section 2 reflects on the current conceptualization of the concept through the lenses of law and governance, pointing out four aspects of potential enrichment. Building on these reflections, in Section 3 we suggest how governance and legal insights can be incorporated into the solution space concept. Finally, in Section 4, we reflect upon the implications of our findings for interdisciplinary and transdisciplinary research more broadly and provide recommendations for future research.

2. Reflections on the *'solution space'* concept through lenses of law and governance

Originally applied in mathematics to indicate the range of solutions for equations (Ar, 1967) in the 1960s, the term 'solution space' was widely applied in various disciplines, including biology (Bordel et al., 2010), energy science (Robinson and Rahmat-Samii, 2004), vehicle engineering (Zimmermann and von Hoessle, 2013), software engineering (Berg et al., 2005), and behavioural science (Licalzi and Surucu, 2012). In sustainability science, it was developed as a key concept in a sustainability assessment tool – Sustainability Solution Space[4] – that has been used for analysing and assessing the sustainability of systems such as the value-added chain for milk (Binder et al., 2012) and in urban planning (Wiek and Binder, 2005). In the aforementioned literature, the concept of solution space has been mainly applied in the natural science domain.

Unlike the earlier applications of the concept referred to above, the latest application of the concept in the field of climate adaptation is a multi- and interdisciplinary approach that aims to integrate a wide range of disciplines, including both natural and social sciences, in a single assessment tool.

[2] Maladaptive space is a figurative 'space' in decision-making process where some chains of decisions lead to maladaptive outcomes over time (Wise et al., 2014, p. 326). Maladaptation has been defined as 'action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups' (Barnett and O'Neill, 2010, p. 211).

[3] Shared socio-economic pathways are a new set of alternative pathways of future societal development (O'Neill et al., 2017; p. 169). Socio-economic scenarios are used to derive emissions scenarios without climate policies (baseline scenarios) and with climate policies (mitigation scenarios) (Riahi et al., 2017).

[4] Sustainability Solution Space is an assessment tool based on a geometric approach. It comprises a multifaceted, comprehensive indicator system, an integrative system analysis, and a sustainability assessment. It is applicable to any problem area in which the sustainability of a complex system has to be analysed and assessed holistically (Binder et al., 2012)

2.1. The first reflection: on the context specificity in legal and governance systems

It has been claimed that the solution space 'can be applied to any administrative scale (e.g. global–local), climate impact (e.g. flood risks), actor group (public or private), or system of concern (e.g. supply or value chains) and evolves over time' and across contexts (Haasnoot et al., 2020, p. 2). However, we argue that although this contention acknowledges the diversity of socio-economic conditions, values, and interests amongst countries, communities, and individuals, it needs to be refined. It should be specified *how* the same conceptual framework could be applied to different contexts (e.g. a country or a region) to respond to the complexity of the real world. To avoid oversimplification, the investigation to answer this question must include the comprehensive environmental and climate regulatory regimes of that jurisdiction, as well as the administrative institutions and stakeholders operating and participating in climate adaptation action at all scales.

An added complication is that, 'the shape of the solution space is in constant flux' (Haasnoot et al., 2020, p. 2) and thus the boundary conditions, impacts, and affected interests are labile too. The legal and institutional implications of this mutability relate to the fact that society cannot simply be treated as a laboratory for testing climate adaptation solutions, because every such solution is a 'one-shot operation': once it has been implemented, the societal playing field changes, sometimes irreversibly (Rittel and Webber, 1973). Thus, the conceptual framework of solution space needs to embody rules and institutions that can minimize irreversible consequences and balance the interests in the 'constant flux'.

The current concept of solution space generally treats political and socio-economic changes as resulting from exogenous changes in the biophysical system. Furthermore, it categorizes 'laws and regulations' as well as elements of governance (such as 'awareness raising' and 'interests coalition') as 'planned actions', which 'intentionally shape the solution space' (Haasnoot et al., 2020, Table 1). Such a perspective might be seen as too optimistic regarding the potential of human agents to intentionally steer developments in socio-ecological systems (for an informed critique, see Hajer et al., 2015). Moreover, this kind of categorization excludes legal and governance perspectives from the early stage of *defining* the changes that influence the solution space. Legal and governance elements can contribute to the shaping of solution space as early as the biophysical changes because the rules, processes, and institutions of a legal or governance system inherently constitute boundary conditions for the solution space. For instance, a country's common law or civil law system inherently determines the major sources of law as well as the legislative process. Such a legal tradition or culture shapes the boundary conditions of the solution space concomitantly with the biophysical system, instead of being a 'planned action' in response to the latter. Early involvement of legal and governance dimensions in climate adaptation is important because climate adaptation is a wicked problem (Rittel and Webber, 1973), as it lacks a well-structured policy domain and knowledge about climate change is uncertain and contested (Termeer et al., 2013; Triyanti et al., 2020). Due to these characteristics, defining problems that need solving and devising the corresponding solutions become a highly value-laden, political act, making it more important to incorporate legal and governance insights in the phases of scoping and defining the problem. Examples of potentially useful insights are the political objective of sustainable development and the corresponding legal obligations. To enable inclusive action to define a problem, it is necessary to establish mechanisms and forums for early involvement of legal and governing actors.

2.2. The second reflection: on the dynamic and reflexive legal and governing systems

Another characteristic of the solution space concept is that the solution space is path-dependent. It includes decision path dependency

(decisions taken now will influence the future solution space) and scenario path dependency (biophysical or socio-economic changes determine the range of future available options) (Haasnoot et al., 2020).

From legal and governance points of view, defining path dependency is an arduous task, due to the inherent reflexivity of legal and governance systems. The current political, institutional, and legal systems do indeed contribute to path dependency, but such systems can at the same time also break the path dependency (e.g. by promulgating new regulations or changing the interpretation of existing legal norms when the current norms obstruct the disruptive but desirable social changes) (Hegger et al., 2020; Heldeweg, 2017). For instance, a country's land-use regime largely determines the range of adaptation options in response to flooding (e.g. alternative modes of farming), which might exclude some types of land-use options. Authorities responsible for land use respond to this by reflecting on the ecosystem change and authorizing such a land-use change. This process of contributing to and breaking path dependency may be iterative.

The characteristic of reflexivity makes the legal and governing systems inherently different from the biophysical system. For instance, sediment flows or sea-level rise cannot themselves respond to knowledge of their impacts. Social processes, however, can be and are influenced by actors' views on the social system, as well as by new knowledge about biophysical systems. This phenomenon, referred to as 'double hermeneutics' in social sciences, applies to sustainability studies (Audet, 2014; Hegger et al., 2020).

2.3. The third reflection: on the methodology

The current solution space framework offers scope for elaborating on how to conduct a holistic approach. Such an approach requires the integration of methods commonly applied in legal and governance research.

In terms of the methodology for operationalizing the solution space concept, the main problem of incorporating legal and governance dimensions is that it is difficult – even impossible – to quantify them. Because the approach is a scenario-mapping tool for decision making, to determine the optimal solution for now or the future it relies strongly on quantitative evaluation, or at least a classified appraisal (e.g. low, medium, and high) of each dimension.[5] However, from a legal and governance perspective, such a method might have only limited helpfulness.

We acknowledge it might be worthwhile to identify quantifiable indicators of the presence of governance and legal approaches, such as the availability of regulatory instruments, or the number of available instruments that allow or prohibit certain behaviour; these can be understood as determinants that broaden or narrow the solution space, due to regulatory constraints. But such a focus on quantitative indicators ignores various crucial determinants of the legal and governance-related solution space. It fails to consider that there is neither deterministic causation nor linear correlation between a policy and certain effects. In other words, having more institutions or regulations available does not necessarily give rise to more action. On the contrary, in some cases, it might indicate institutional complexity or a lack of enforcement. More interpretative approaches are needed to appreciate the qualitative differences between different legal and governance approaches. For instance, methods of legal reasoning and interest balancing commonly applied in legal and governance research may generate different results from applying the same policy. Many norms in legal reasoning are open-ended, leaving scope for legislative interpretation or judicial discretion in response to societal changes (Himma, 1999; Lyons, 1999). In governance research, decisions are often based after weighing up the impacted interests and facts in a specific situation, guided by ethical principles (e.g. the selection of a location for controlled flooding) (Dai, 2019).

2.4. The fourth reflection: on normative principles

Haasnoot et al. (2020) argue that the boundaries of the solution space are flexible and will change in form and size over time and across contexts. Although the boundary conditions range from biophysical to political–institutional ones, the *normative* dimension regarding the prescriptive statement and/or value judgement of 'what *should* or *should not* be done' remains underexposed, although it is not explicitly excluded. This criticism echoes earlier criticisms by legal and governance scholars of overly simplistic conceptualizations of law and governance (Driessen and Van Rijswick, 2011). In contrast to most research approaches that apply the solution space concept without a normative consideration, the Sustainability Solution Space assessment tool (mentioned at the beginning of Section 2) includes a normative dimension that mainly refers to values, goals, and the interpretation of the concept of sustainability in different contexts (Binder et al., 2010), but legal or governance principles remain excluded.

From legal and governance points of view, the assessment of the solution space should take into account normative principles to be meta-governance considerations for guiding the selection of appropriate solutions, and should include substantive principles that might limit or change the solution space (e.g. legitimacy, equity, and distributive justice), and procedural principles that organize the process of making decisions on selecting certain pathways within the solution space (e.g. transparency, accountability, and participation). The principles not only play a safeguarding role, as citizens' rights must be respected and protected, and allocation of costs and benefits between different regions and socio-economic groups must be balanced at (or even above) the national level, but also provide the rationale for negotiating alternative solutions proposed by stakeholders with diverse interests.

3. Approaches to enhance governance and legal dimensions in the solution space concept

Elaborating on the reflections introduced in Section 2, Section 3 will demonstrate how to enrich governance and legal dimensions of the current solution space concept.

3.1. Re the first reflection on context specificity

In the first reflection, we observed that potential solutions are highly situated in time and space. Due to this context specificity, legal and governance dimensions of the solution space concept need to be enhanced by 1) understanding the regulatory and institutional systems in the given context, 2) applying appropriate institutional tools to deal with the consequences of 'one-shot operations', and 3) creating mechanisms for early involvement of legal and governing actors in defining a problem.

3.1.1. Understanding the regulatory and institutional systems in the given context

The current solution space concept has provided a good basis for understanding the natural system's biophysical factors. However, more attention should be given to unpacking the complexity of the social and governing systems. We argue that, to this end, the notion of 'room for manoeuvre' (RfM), alluded to by Haasnoot et al. (2020) and described in more detail by Kronik and Hays (2015), deserves to be elaborated more fully, as it improves the understanding of the societal dimensions of the solution space concept. Kronik and Hays (2015) argue that not only exogenous forces but – and equally importantly – values, perceptions,

[5] In line with" Haasnoot et al. (2013), the assessments are based on the proposal for the framework for adaptation pathways and dynamic adaptive policy pathways, and biophysical factors, which are mostly quantifiable. In Haasnoot et al. (2020), 'adaptation pathways' are proposed as ways to map adaptation options and their path dependency within and outside the solution space.

processes, and power structures within a society limit societal adaptation. To support effective adaptation, rather than using the solution space concept, it is better to use the notion of RfM, because it 'better captures the decision-making processes that take place within local socio-ecological systems, including cultural practices, institutions and knowledge systems, and relates these to opportunity structures and sources of pressure' (Kronik and Hays 2015, p. 25).

Governance systems consist of a set of actors on multiple levels, including governmental agencies, civil society, NGOs, businesses, and the private sector. Furthermore, governance systems have diverse structures, and instruments (e.g. regulation, financing, communication, and infrastructure), as well as modes of governance (e.g. hierarchical, co-governance, self-governance) that operate diversely and at different scales (Driessen et al., 2012; Vink et al., 2013). The issue of institutional fragmentation, for example, is prominent in climate adaptation practice, as the governing actors each have their own goals and instruments for climate adaptation (Runhaar et al., 2018; Triyanti et al., 2020). There are also diverse interests at stake and there are dynamic power relationships between different actors (Wamsler and Raggers, 2018), especially in the case of climate change adaptation, where there is inequality in terms of vulnerability to climate change impacts and imbalances of decision-making power and resources for climate change adaptation (Nightingale, 2017; Scoville-Simonds et al., 2020; Thomas and Twyman, 2005). For example, the politics of mainstreaming climate change adaptation in the Global South have often resulted in the reinforcement of technocratic solutions (Mikulewicz, 2020; Scoville-Simonds et al., 2020) without addressing the root causes of problems and the importance of societal transformation. Understanding the specific characteristics and contexts of the natural and social systems at work, their governance systems, and their interactions (Kooiman and Bavinck, 2013), including power relations, is, therefore, crucial in order to design appropriate climate adaptation strategies.

In terms of the legal and policy regimes, the context specificity first concerns the legal instruments shaping the legal boundaries of the solution space for climate adaptation at different scales and sectors. The first step of investigating such instruments is to check the availability of specific climate legislation in the targeted jurisdiction. National climate legislation is still unavailable in most jurisdictions,[6] and some climate laws merely deal with climate change mitigation (e.g. Dutch Climate Act). Despite the unavailability of climate legislation in most cases, it is common to find that a national strategy, programme, or plan has been articulated in the form of rule-based policies (e.g. national policies that internalize obligations under the Paris Agreement) to elucidate climate adaptation strategies and tasks to strengthen resilience and reduce vulnerability. The main distinction between climate legislation and policies lies in the binding force of the targets and tasks stated in the instruments. In general, legally binding rules and procedures can provide clearer boundaries around solution space.

The legal set-up for environmental protection and natural resource conservation and use not only comprise legal instruments directly addressing climate adaptation but also include provisions that are indirectly applicable to such action. Among the most common legal instruments available in jurisdictions with modern legal systems are the laws on environmental protection, water resources, forestry, land use and building, and disaster management. Normally, climate adaptation is not explicitly addressed in these legal instruments. The usual way of addressing climate adaptation is by mainstreaming climate change concerns into the declaratory provision of a specific law, or by stipulating measures to fulfil the objective of such a specific law, with adaptation as a co-function or welcome side-effect. For instance, it is common to find a provision on ex-situ conservation of species under the law on biodiversity when in-situ conservation is no longer possible. Even though such a provision has not been expressly designed for climate adaptation, it can be applied if habitats change due to climate change.

The rules associated with climate adaptation are the focus of the legal dimension of context specificity. Nonetheless, targets and tasks regarding greenhouse gases mitigation are still relevant, because how mitigation action is undertaken influences the degree of adaptation action and, therefore, contributes to shaping the future adaptation pathways (Lee et al., 2020; Swart and Raes, 2007).

3.1.2. *Applying appropriate institutional tools to deal with the consequences of 'one-shot operations'*

The second point regarding the context specificity of governance and legal systems relates to the rules, procedures, and mechanisms that address the consequences of one-shot operations (as explained under the second reflection in Section 2). Procedures and mechanisms concerning ex-ante impact assessments, monitoring the implementation and enforcement of adaptation obligations, and allocating responsibility for climate adaptation activities between institutions and across hierarchical levels (Green et al., 2014; Gunderson et al., 2017; Mees et al., 2013) are crucial to prevent or minimize irreversible consequences of one-shot operations.

Among the most relevant provisions contained in the legal and institutional dimension of the solution space concept are arrangements for monitoring disasters, balancing interests, sharing information, building capacity, collaborating across different scales, and participatory decision making. In the literature it has been argued that the most appropriate governance for dealing with climate change is polycentric, since it embraces the participation process by making more space for more actors (Jordan et al., 2018; Ostrom, 2014). For example, in the case of dike reinforcement projects in the Netherlands, the introduction of other types of measures, including creating wider washlands for the major rivers, has triggered a shift from centralized to more polycentric modes of governance that have proved to be more effective in ensuring water safety (Wiering and Driessen, 2001). In terms of interactions, climate adaptation strategies need to be well-coordinated, as a decision (often made by the national government) to employ specific instruments (regulatory, financial, infrastructural, and communication) singly or in combination (Henstra, 2016; Mees et al., 2013; Vogel and Henstra, 2015), could affect the community on the frontline. Therefore, effective multi-level coordination and a clear division and alignment of responsibilities are needed (Gilissen et al., 2015). On top of all this, a power-related issue could prevent the governance process from achieving climate adaptation goals (Nightingale, 2017; Thomas and Twyman, 2005). The power may play out vertically (conflict of priority and discourses between different levels of government (national to local) under the centralization and decentralization debate: Brockhaus and Kambiré, 2009), or horizontally (conflict among various governing actors (e.g. civil society and private sectors): Newell, 2008).

Governance capacity must also be adequate when the 'one-shot operation' is being implemented. The required capacity may be *knowing* (understanding the possible impact of certain policies/actions), *wanting* (commitment to collaborate and use the skills of governing actors to find solutions), and *enabling* (support systems, such as networks, resources, and instruments) (Koop et al., 2017). Governance capacity is developed through learning: single-loop learning (the capacity to improve a simple structured problem), double-loop learning (the capacity to improve direct drivers), and triple-loop learning (the capacity to address principles with transformative methods) (Gupta, 2016).

3.1.3. *Creating mechanisms for involving governing actors in defining a problem*

The third point regarding context specificity of governance and legal systems relates to the mechanisms for collecting knowledge and promoting participation: these mechanisms require or facilitate the early

[6] Exceptions are the national climate change acts of some EU Member States, such as those of Denmark (2014), Finland (2015), France (2015), Sweden (2017), the Netherlands (2019), Germany (2019). The UK promulgated its Climate Change Act in 2008.

involvement of legal and governance actors early in defining a problem. Adapting to climate change entails comprehensively understanding a system and its problems. Knowledge from both the natural and social systems (and their interconnectedness) is crucial when identifying current and future problems (see e.g. Koop et al., 2017; van Rijswick et al., 2014). Knowledge on the natural system is obtained by assessing sea-level rise, hazards, and climate-related disaster risks, such as flooding or droughts. Knowledge of the social system requires understanding the social aspects affecting a community's vulnerability to climate change impacts. Vulnerability is affected by factors such as population growth, urbanization processes, poverty, and social conflicts (Downing and Patwardhan, 2005; Eriksen and Kelly, 2007). Furthermore, when planning climate adaptation strategies, it is necessary to assess their impacts in terms of loss and damage and to perform cost-benefit analyses of certain strategies (Agrawala et al., 2011; Bosello et al., 2010). Gathering this knowledge requires appropriate governance approaches, including a mechanism for facilitating diversification of worldviews and knowledge from scientific actors and other stakeholders to define the problems and their causes. This type of mechanism is also important to validate the relevant knowledge and for social learning.

The mechanisms associated with information sharing and stakeholder participation are highly relevant for the early involvement of legal and governance actors in the process of defining and resolving climate change issues. Internationally and regionally, legal and governance actors can play a vital role regarding the rulemaking for climate change negotiations in international arenas and by facilitating broad collaborations across national boundaries. For instance, actors with a background in international law and international relations could contribute to designing mechanisms for international cooperation (Knox, 2009) and for defining progress in mitigation and adaptation action (e.g. the updates of Nationally Determined Contributions under the Paris Agreement).

3.2. Re the second reflection on the dynamics and reflexivity of law and governance

Essential to showing how insights from governance and legal studies can help enrich current understandings of path dependency as embodied in the solution space concept are the realization of the different connotations of 'changes' in social sciences and the integration of the feature of 'double hermeneutics' into the connotation of path dependency. This can be facilitated by acknowledging that in the concept of solution space, legal and governance systems are adaptive and therefore continuous reflection is possible on the new knowledge about both natural and social systems and the corresponding iterations of rules and processes to re-evaluate their validity.

Dynamics in natural systems are usually perceived in terms of physical circumstances, such as the rates of sea-level rise, the probability of climate-related hazards such as floods and droughts, and the responses to deal with these impacts, such as through building physical infrastructure. However, dynamics also occur at the interface of natural and social systems and within the social system itself. At the interface, changes in the social system occur when responding to the natural system dynamic, including dynamics in the institutional and policy domains. Agencies and interventions (e.g. physical infrastructures, but also social infrastructures such as safety norms and substantive rules) can fluidly change to deal with certain shock events (Hegger et al., 2020). In such instances, certain policy arrangements can help temporarily stabilize the dynamics of the policy domain (van Tatenhove et al., 2000).

In the case of flooding, the natural system dynamics can interact with the dynamics of the social system as follows: high exposure for communities living in unprotected areas coupled with a low probability of successfully evacuating them (Hegger et al., 2014). These dynamics provide the governing actors with an opportunity to think beyond emergency and recovery attempts by focusing more on reducing flood risk by diversifying actors and ensuring appropriate instruments and strategies are in place (Hegger et al., 2014). This shows that dynamics could serve as an opportunity not only to endure but also to adapt and transform to a desirable trajectory (i.e. climate resilience), as highlighted in the evolutionary resilience concept (Davoudi et al., 2013).

The reflexivity of law responds to the requirement of dynamism in socio-ecological systems by ensuring legislation can adapt to uncertainties. In part, the reflexivity of law concerns procedural mechanisms for bottom–up feedback and iterative reviews based on diagnostic monitoring and new scientific insights (Garmestani and Benson, 2013). It also concerns regulatory or policy experiments and sunset clauses that allow trial and error and encourage innovation in policy-making (Decaro et al., 2017). To reduce the difficulty and costs of making changes, the preferred law-making techniques are principles or open norms rather than quantified standards (Ruhl, 2010, 2011).

When promoting the reflexivity of law, it is important to emphasize a balance between legal certainty and enforceability vis-à-vis flexibility (van Rijswick et al., 2014). Legal certainty is important for shaping the solution space because the predictability of law guarantees basic path dependency and legitimizes long-term legal stability.

3.3. Re the third reflection on the methodology

Debate about epistemological differences in methodology is not infrequent, especially in the context of multi-or interdisciplinary research. To enrich the concept of solution space, one should take a step back and explore diverse methods of assessing boundary conditions.

We can draw several insights from diverse concepts and methodologies. But first, it is imperative to develop an integrated approach combining natural and social science perspectives to study a system. Several frameworks, such as the ten building blocks for water governance (van Rijswick et al., 2014) and the Institutional Analysis and Development framework (IAD) (Ostrom, 1990, 2011) arrive at effective solutions by ensuring the input of socio-economic, governance, and biophysical systems knowledge. Exploring this integrated knowledge is crucial to understanding the functional interdependency of socio-ecological systems (van Rijswick et al., 2014). Furthermore, studies have highlighted the importance of co-defining problems and using a shared vocabulary and goals to find appropriate solutions to sustainability problems (Bodin, 2017). One way to facilitate this process could be to develop a community of practice consisting of relevant stakeholders; this will enhance the capacity to co-diagnose the problems and to contextualize the solutions in the many action arenas (e.g. rules and regulations) (Ostrom, 2011, 1990). A parallel process of accumulating knowledge on socio-ecological complexity and decision making (Giebels et al., 2013) can be instigated, to enhance the effectiveness of devising and implementing certain measures (van Rijswick et al., 2014).

The second insight is that it is possible to combine methods, for example, by using multi-criteria analysis. Take the example of a sustainable livelihood framework (Elasha et al., 2005; Scoones, 1998), in which the context, conditions, and trends are first analysed, including natural conditions (i.e. climate and agro-ecology) and socio-economic factors (i.e. history, politics, economy, and social differentiation). The multidisciplinary nature of the framework also extends to the second and third steps of the analysis, to yield livelihood strategies and sustainability strategies (Elasha et al., 2005; Scoones, 1998), where different capitals e.g. (natural, social, financial, human) and institutional structures are assessed. To explore the interlinkages between natural and social systems and to produce effective strategies, this framework, the ten building blocks and IAD frameworks all propose using an approach that is simultaneously multi-, inter-, and transdisciplinary.

Finally, by presenting these diverse methodologies, we argue that qualitative types of research and transdisciplinary approaches should not be seen as impediments in integrated research, but rather as instruments to explore the interlinkages between natural and social systems and to produce effective strategies for impactful research focusing

on implementable and sustainable solutions. We therefore propose these methodologies be used as inspiration for operationalizing the solution space framework. In addition, we believe that the complex governance, legal, socio-economic, and political problems should be addressed early on in the research process, as this is likely to increase the effectiveness of the implementation of a solution. The issue of achieving agreement about problems, for example, could be solved by engaging with the real stakeholders on the ground and taking their experience on board. This approach also applies to the problems arising from conflicting disciplinary language and terminologies that often arise in multi-, inter-, and transdisciplinary research. By paying more attention to these complementary methods and longitudinal approaches (Dai, 2019; Wuijts et al., 2018), it will be possible to enhance the relevance, applicability, and transformative potential of such frameworks in the policy-making domain.

3.4. Re the fourth reflection on the normative principles

Normative principles in the conceptual framework of solution space have been established in response to the overarching governance questions, namely how to guide the institutional and problem-solving choices, how to underpin future-oriented activities, and how to appraise governance activities (Driessen and Van Rijswick, 2011; Kooiman and Jentoft, 2009). As a concept comparable to solution space, the RfM concept recognizes the need to *create* 'the *right* kind of space, and to facilitate appropriate, innovative, and creative adaptation that retains principles of equity and social justice as its core' (Thomas and Twyman, 2005). For instance, even if the option of building flood defence infrastructure proves to be feasible under specific socio-economic conditions, it should not be selected if it is irreconcilable with certain normative principles.

The foregoing example demonstrates that the logic of consequences and the logic of appropriateness should be considered simultaneously (Schulz, 2016). The former refers to actions driven by analysis-based, deliberate choices of alternatives, which in the case of solution space are associated with the assessment of issues to do with the effectiveness, efficiency, and feasibility of climate change adaptation measures ('will they work?'). The logic of appropriateness, on the other hand, refers to actions shaped by the rules applying in a specific situation. Rules may be implicit (e. g intuition, habits, skills, routines, experience, and knowledge) or explicit (e.g. policies, bureaucratic rules, norms, and institutions) (Schulz, 2016). The key point of the logic of appropriateness is that certain actions or solutions are rule-specific and based on a defined situation. Examples of governance principles that are commonly associated with the logic of appropriateness are those of legitimacy, transparency, accountability, equity, and distributive justice.

We hold that the selection of adaptation measures should be guided not only by the logic of consequences but also by the logic of appropriateness. This logic may help determine whether proposed solutions would be acceptable for reasons other than their expected effects on the physical system. Paradoxically, because they fit better with their geographical and institutional context, appropriate solutions might also contribute to more effectiveness in terms of reducing vulnerability and risks arising from climate impact and of increasing the sustainability of adaptation measures.

Legitimacy has been investigated in studies in a wide range of disciplines, including law (Bodansky, 2008; Fallon, 2012), sociology (Johnson et al., 2006), politics (Stillman, 1974; Suchman, 1995), and international relations (Andersen, 2012). From a legal perspective, legitimacy incorporates the lawfulness of behaviour as regulated by authorities (positive laws), as well as the correctness (justness) or reasonableness as a matter of law (natural laws) (Fallon, 2012). From an institutional perspective, legitimacy refers to the justification and acceptance of political authority, based on, for example, tradition, expertise, legality, or public accountability (Bodansky, 2012).

In the context of pursuit of appropriate climate adaptation, the principle of legitimacy requires the fundamental rights of humans affected by climate change to be recognized and protected because the policy debate about climate change has always focused on its human impacts – the harm to coastal communities, agriculture, human health, and human welfare more generally (Bodansky, 2010). The *human rights approach* operationalizes the principle of legitimacy in the context of accelerating climate adaptation action in two aspects. The first aspect is to require the authorities to protect the lives and health of citizens from threats posed by rapid environmental change and its adverse impacts, regardless of whether the authorities themselves are responsible for the changes and impacts (Knox, 2009; Misiedjan, 2019). Second, it requires the authorities to ensure the procedural rights of citizens, in particular their access to information and participation in decision making, when selecting problem-solving options (Bodansky, 2008; Boyle, 2008). The legitimacy framework has been used for assessing governance issues such as flood risk governance (Pettersson et al., 2017).

The principle of *transparency* has broad connotations, the common elements of which include the visibility of the decision-making process, the clarity of the reasoning behind decisions, the availability of information about the performance of authorities, and the provision of public inquiries and independent reviews (Lockwood, 2010; Pettersson et al., 2017). The principle of *accountability*, however, goes beyond transparency, requiring not only the communication of information and performance but also that the governing body is answerable to stakeholders for its performance (Lockwood, 2010; Mees and Driessen, 2019).

Being aware of the broad discussion on the principles of transparency and accountability across disciplines, we narrow down to the relevance of transparency and accountability for promoting legitimacy (Alexander et al., 2018). In the domain of flood management, the lack of transparency when declaring disasters undermines the system's legitimacy (Suykens et al., 2016). Accountability, too, is treated as an intrinsic component of legitimacy, as governing bodies should be answerable to the people from whom they derive their legitimacy (Lockwood, 2010). In response to complex environmental problems characterized by spatio-temporal interdependencies, cross-scale interactions, and high uncertainty (such as climate adaptation), accountabilities need to be extended from public sectors to private actors, and be grounded in citizens' participation (Birnbaum, 2016; Cosens, 2013; Mees and Driessen, 2019).

Other highly relevant normative principles are the principles of *equity and distributive justice.* These are ethical issues frequently mentioned in the discourse on climate change (Driessen and Van Rijswick, 2011; Thomas and Twyman, 2005; van Doorn-Hoekveld et al., 2016). In the context of climate adaptation, equity and distributive justice encompasses the distributive effects of climate change impacts and the allocation of natural resources and economic advantages in adaptation activities (Klinsky and Dowlatabadi, 2009). In delta regions, different methods of pursuing climate resilience – resistance, adaptation, or transformation – could give rise to common problems concerning distributive justice (Triyanti et al., 2020). For instance, the adaptation to new livelihood patterns may exacerbate the unequal distribution of water resources and competing interests involved in irrigation management (Suhardiman and Giordano, 2014; Waibel et al., 2012). In a 'retreat' scenario, distributive justice issues are often embedded in deliberate migrations of residents (Lindegaard, 2020) and reflect concerns such as the decision-making processes and the mechanism to compensate for land-use changes (Dai, 2019).

The main implications of equity and distributive justice for legislation associated with legal solution space for climate adaptation include 1) the norms intended to reduce the vulnerability of the communities who are sensitive to ecosystem changes and are frequently exposed to disasters; 2) procedures for selecting prioritized adaptation solutions, considering the limited resources (both natural and financial), as well as the diverse socio-economic conditions of different regions; and 3) the access to and equitable use of land, water, and other natural resources, and the mechanisms compensating for ecological services. From a

governance perspective, equity and distributive justice exist when all relevant actors are acknowledged as governing actors that co-define the problems, common goals, instruments, and actions and share the responsibilities and benefits.

4. Discussion and conclusion

We summarize our approaches to incorporate legal and governance aspects in Table 1 below. Note that the four key contributions from governance and legal studies do not stand on their own but are interrelated.

This article has engaged with prominent and timely debates on how to develop forward-looking approaches for climate change adaptation. Although several valuable interdisciplinary contributions have been added to this debate, including the solution space concept, we find that the treatment of governance and legal dimensions nevertheless needs strengthening. Therefore, this article has aimed to contribute to enriching the concept of solution space for climate adaptation by unpacking its legal and governance dimensions. A deeper understanding of these dimensions is crucial, not only for defining clear boundary conditions for adaptation solutions but also for defining the problem at issue at the outset of an interdisciplinary research process, as well as the policy- and decision-making processes.

The features of social systems determine that there is not always *one* optimal solution to a problem. A better understanding and elaboration of the legal and governance dimensions will ensure that certain solutions are not only technically feasible but also appropriate and can accelerate effective climate change adaptation in the longer term. We argue that the legal and governance dimensions of the current concept of solution space can be improved by taking account of four aspects: 1) understanding the institutional and legal systems in a context-specific way; 2) embracing the dynamics and reflexivity of law and governance in the episteme of path dependency; 3) applying more diverse analytical methods (qualitative, or a combination of qualitative and quantitative, value-oriented) and/or assessments on a case-by-case basis; and 4) adding a normative perspective which contains, among others, the principles of legitimacy, transparency, accountability, equity, and distributive justice, to measure the appropriateness of a certain adaptation strategy. By taking into account these four aspects, the solution space concept will move beyond mere instrumental use of governance and legal insights, where its role is limited to the 'implementation' of technically defined problems and solutions.

In addition to its academic contribution to enriching the solution space concept, this article also presents a possible way of delivering shared understanding across disciplines, including the domains of natural and social sciences. The four points of reflection and the corresponding approaches to incorporating legal and governance insights addressed in this article could be useful for broader audiences who face the same challenges of including and understanding the social science contributions in an interdisciplinary and/or transdisciplinary research process, as well as the process of developing climate adaptation policies. The respect for normative principles, the attention to distinct methodologies, the awareness of double hermeneutics, and the recognition of the complexity of the social system could be common entry points for enriching social science dimensions of an interdisciplinary concept.

Regarding further research, we are aware of the challenges that the implementation of the enriched solution space concept might bring. The potential barriers to using the insights contained in this article are twofold. First, we note that natural and social scientists often have difficulties understanding each other. A common pitfall is that insights from governance and legal approaches are viewed instrumentally, as a way to implement technologically defined solutions to technologically defined problems. Earlier involvement of law and governance will lead to earlier awareness of more normative and political questions, both in terms of research and regarding adaptation processes on the ground. However, such earlier involvement is an ongoing endeavour. Second, although it is changing gradually, the current funding landscape is not always conducive to supporting fully interdisciplinary and transdisciplinary studies. A crucial issue is that research reviewers often seem unfamiliar with interdisciplinary proposals that do not depart from a natural science starting point (Huutoniemi and Rafols, 2017; Langfeldt, 2001). In addition, the evaluation processes of interdisciplinary research

Table 1
Aspects and key contributions from governance and legal studies to enrich the solution space concept.

Aspects for enriching the solution space concept	Key contributions from governance and legal studies	Examples
More attention to context specificity in legal and governance systems	Elaborating the regulatory and institutional systems in a context-specific way.	The climate adaptation legal and policy regime of a jurisdiction.
	Applying appropriate institutional tools to deal with the irreversible consequences of 'one-shot operations'.	Environmental impact assessments, arrangements for monitoring, capacity building, cross-scale collaboration, and participatory decision making.
	Creating mechanisms for early involvement of legal and governing actors in defining a problem.	Mechanisms and forums for information sharing and stakeholder participation.
More attention to the dynamic and reflexive nature of legal and governing systems in the episteme of path dependency	Elaborating institutional dynamics and policy arrangements.	Institutional and policy arrangements (beyond emergency and recovery) that focus on risk reduction.
		Proposing social infrastructure dynamics as responses to natural system dynamics through diversification of actors, appropriate instruments, and strategies.
	Explicating reflexivity of law via procedural mechanisms and open norms.	Periodic review and updates of rules and policies in response to socio-ecological changes.
More attention to interdisciplinary and transdisciplinary methodologies	Proposing complementary methods and multi-criteria analysis by using a combined quantitative/qualitative approach.	The Institutional Analysis and Development Framework, which integrates knowledge from multiple disciplines.
	Recommending longitudinal approaches.	Research examining variables over an extended period: for example, by engaging with stakeholders on the ground and reflecting on their lived experience.
More attention to normative principles	Considering the full range of relevant good governance principles, in particular the principles of legitimacy, transparency, accountability, equity, and distributive justice plus the logic of consequences and the logic of appropriateness.	Legitimacy, transparency, and accountability (each intertwined): ensuring citizens' access to public information and participation in decision making.
		Equity and distributive justice: compensating the communities who are vulnerable to ecosystem changes and very exposed to disasters.

proposals are currently not equipped with adequate standards to measure what is 'good' interdisciplinary research (Laudel, 2006). Through this article, we hope to draw broader attention to those barriers and invite more scientists to reflect on the current practice of interdisciplinary collaboration.

By elaborating the legal and governance connotation in the concept of solution space, we have attempted to gain 'a common vision on the problem' and emphasize the concept's process-based quality, in addition to its results-based quality (Bruzzone et al., 2016). To operationalize our proposed approaches to incorporating legal and governance dimensions, it is important to test them in the interdisciplinary context of the solution space concept and to interact more with other dimensions to see whether our findings do indeed contribute to solving the 'wicked problem' of climate adaptation. One method would be to assess the enabling and disabling conditions contained in each dimension of solution space via specific illustrations, to explore the feasibility for 'real world' application of the concept. Among the many potential and relevant topics to which this connotation of legal and governance in the solution space concept could be applied are water and climate adaptation governance (Triyanti et al., 2020; Gilissen et al., 2017, 2015; Runhaar et al., 2016), flood risk governance (Driessen et al., 2018; Kundzewicz et al., 2018), and coastal ecosystem-based disaster risk governance (Triyanti et al., 2017).

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CRediT authorship contribution statement

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

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.

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