

RESEARCH

Open Access



No easy way out: towards a framework concept of long-term governance

Dirk Scheer^{1*}, Sandra Venghaus², Stefania Sardo¹, Sascha Stark², Sophie Kuppler¹, Michael W. Schmidt¹ and Carsten Hoyer-Klick³

Abstract

Background Problems such as climate change, environmental pollution, nuclear disposal and unsustainable production and consumption share a common feature: they pose long-term challenges because of their complex nature, potentially severe consequences, and the demanding problem-solving paths. These challenges may have long-lasting impacts on both present and future generations and, therefore, require to be addressed through a long-term governance perspective, i.e., coherent and consistent policy-making across sectors, institutions, and temporal scales. Dealing with these challenges is a core task of policy-making in modern societies, which requires problem-solving skills and capabilities. In this context, we identify long-term governance traces in the literature, illustrate the case of energy transition towards renewable energy systems as a long-term governance case, and elaborate on the scope and definition of long-term governance and its research.

Main text We elaborate an analytical framework for long-term governance (LTG), based on five building blocks: the 'environment', which details the policy-making arena; the 'policy issues', which elaborates on the problems to be dealt with by LTG; the 'key challenges and driving force', revealing LTG mechanisms; the 'key strategies', in which promising approaches for LTG are identified; and the 'policy cycle', where governance impacts on different policy phases are discussed. In essence, we understand long-term governance at its core as a reflexive policy-making process to address significant enduring and persistent problems within a strategy-based decision-making arena to best prepare for, navigate through, and experiment with a changing environment.

Conclusions The framework does not describe specific processes or individual cases in detail. Instead, it should be understood as an illustration of long-term governance characteristics at a more general level. Such a framework may help to structure the field of long-term policy-making, guide future research on conceptual, comparative, and empirical in-depth studies, and may provide orientation and action knowledge for making our governance system sustainable. Stimulating and broadening research on long-term issues seems indispensable, given the existence of several 'grand challenges' that require successful long-term governance.

Keywords Long-term governance, Conceptual framework, Grand challenges, Systemic and societal change, Renewable energy systems

*Correspondence:

Dirk Scheer
dirk.scheer@kit.edu

Full list of author information is available at the end of the article



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

Background

Problems such as climate change, environmental pollution, nuclear disposal and unsustainable production and consumption share a common feature: they pose long-term challenges because of their complex nature, potentially severe consequences, and the demanding problem-solving paths—often linked to high hopes attached to technological developments and implementation, which mark them as “socio-technical problems”. Addressing these challenges will require fundamental changes to the status quo, as their root causes are deeply embedded in the structures and practices of modern societies, bringing about changes that will have long-lasting impacts on both present and future generations [1–6].

Dealing with these long-term challenges is a fundamental aspect of policy-making in modern societies, necessitating the implementation of problem-solving decision-making strategies. In essence, it requires the implementation of a long-term governance architecture that coherently copes with the problem through an adequate policy-making process. On the problem side, issues must first be recognized at the societal level. Through complex political processes, which also rely on the insights of various experts, issues are identified as “priorities” by policy makers, leading to their inclusion in specific policy agendas. This process will inevitably take time, because, for instance, the consequences and side effects of a problem may only become fully apparent over time [7, 8]. A major challenge on the policy-making side is to develop and agree on policy options that are feasible within existing constraints and find legitimacy among stakeholders, voters, and society at large. In addition, myopia resulting in short-term policies and compartmentalized structures resulting in silo policies are a major difficulty in policy-making. Long-term problem causes and policy solutions are indeed intertwined and interdependent, potentially creating self-reinforcing and amplifying effects. Thus, temporality is a key feature of long-term governance. While there is no consensus in the literature on the meaning or definition of the time scale inherent to “long-term” policy problems [9, 10], it is important to acknowledge that the time-horizon is specific to different policy issues [11] and also differs depending on the individual and organizational department or practice [12]. For instance, the conservation of biodiversity and the regulation of biogeochemical flows must be maintained over an extended period to be effective [13]. Geological storage of carbon dioxide or nuclear waste calls for continuous management under stable institutional safeguards and communication systems for centuries and more.

Against this background, the aim of this paper is to elaborate an analytical framework for long-term governance. This framework aims to better understand the long-term governance environment and the pending issues, challenges and key strategies and their implications in the policy-making cycle. As a framework, it does not detail specific processes or single cases, but is an illustration of long-term governance characteristics at a more generic level. Such a long-term governance framework can help structure the long-term policy-making field, guide future research on conceptual, comparative, and empirical studies, and provide orientation and action knowledge to enable governance systems to be fit for sustainability challenges.

The paper is organized as follows: within this background section, we first identify long-term governance traces in the literature. Next, we briefly illustrate the case of energy transition towards a renewable energy system as a long-term governance case study, and finally, we outline the scope and a definition of long-term governance and its research. The main section lays out the long-term governance framework according to several building blocks, i.e., the long-term governance environment, long-term governance issues, major challenges and driving forces, substantial key strategies, and considerations of long-term governance within the policy cycle. Finally, we discuss the main results and draw conclusions.

Long-term governance traces in the literature

Our understanding of long-term governance provides many links to several strands of literature—although literature that explicitly addresses the notion of long-term governance is rare. We draw on the following four areas of research: governance literature provides us with ideas about the structures and processes of policy systems and policy-making; earth system governance explores the global scale of environmental risks and their institutional handling; risk research provides knowledge about threats and their systemic and sometimes hidden cause-and-effect relationships; and transition studies explore how change processes can be conceptualized and governed.

The field of *governance research* is essential for the concept of long-term governance. The term *governance* ultimately derives from the Greek verb kubernaein [kubernáo] (meaning to steer). In its current understanding, the term has gained popularity in the 1980s and 1990s, indicating changes about the way political decisions and implementations are made. Governance is generally defined as the interplay of actors and institutions, as well as structures and processes [14], but this concept also encompasses the process by which societies adapt their rules to new challenges [15]. This can happen by integrating various perspectives, often including

a substantive dimension (“What are the rules?”), a procedural dimension (“How are the rules developed?”), and a structural dimension (“Which rules are established, how are they implemented and enforced, and how are conflicts over them resolved?”) [16]. However, there is no common understanding of what governance entails. Three different meanings of governance have been summarized by Fukuyama [17]: governance as the regulation of social behaviour through networks and other non-hierarchical mechanisms (governing without government), governance as public administration (good governance), and governance as international cooperation through non-sovereign bodies outside the state system (international governance).

Governing long-term challenges will often entail aspects of all three meanings. As framed by Nye and Donahue [18: p.12], governance, therefore, means “the processes and institutions, both formal and informal, that guide and restrain the collective activities of a group”. These activities are usually aimed at providing public goods [19, 20]. However, scholars have observed a significant shift since the 1970s, which can be summarized as a shift from government to governance. As Renate Mayntz puts it [21: 18]: “For a long time, the word ‘governance’ simply meant ‘governing’, government seen as a process. Today, however, the term ‘governance’ is mostly used to indicate a new mode of governing, different from the old hierarchical model in which state authorities exert sovereign control over the people and groups making up civil society [...]. ‘Governance’ refers to a basically non-hierarchical mode of governing, where non-state, private corporate actors (formal organisations) participate in the formulation and implementation of public policy”.

While governance research describes the processes and structures of cooperation and coordination among different actors irrespective of time, *earth system governance* explicitly addresses long-term challenges [22]. This field is concerned with the interrelated institutions, organizations, formal and informal rules, and mechanisms through which humans govern their relationship with the natural environment. It focuses on how such governance can be more effectively and equitably aligned with the goal of sustainable earth system transformation [23, 24]. Indeed, human activities have profoundly affected planetary biogeophysical systems to the extent that they may be driving the Earth system into “alternative modes of operation that may prove irreversible and inhospitable to humans and other life” [24: p. 278]. Thus, a global governance architecture might be needed to “steer societies towards preventing, mitigating, and adapting to global and local environmental change and, in particular, Earth system transformation” [24: p. 279]. This architecture is composed of public and private institutions, principles,

procedures, and norms that insist on a particular (problem) area. However, this governance can be quite fragmented, for example, in relation to the perceived scale of the problem [23]. When dealing with earth system governance problems, attention must be paid to dimensions, such as the effectiveness and efficiency of institutions and the consequences of their interactions (the problem of architecture), the capacity of agents (i.e., actors having the legitimacy and authority to exercise power) to purposefully steer earth system transformations (the problem of agency), the ability of groups of agents to adapt to the challenges caused by these transformations, including issues of injustice (the problem of adaptiveness), issues of accountability and legitimacy, and questions of allocation and access [24].

In the field of *risk research*, the study of how societies deal with risks, represents a major source of insight for long-term governance. Modern societies have evolved into a risk society, according to Ulrich Beck, where the pursuit of wealth and economic development “is systematically accompanied by the social production of risks” [7: p. 19]. Let us highlight one important topic in risk research among many others relevant for long-term governance: systemic risks. These risks can “endanger the functionality of systems of critical importance for society and their scope in time and space” [25: p. 2]. They possess several attributes: they are highly interconnected and intertwined, leading to complex causal structures, and exhibit nonlinear cause–effect relationships [25, 26]. In addition, they are stochastic in their cause–impact chains, leading to increased uncertainty that is challenging or impossible to characterize through statistical confidence intervals. Finally, the consequences of systemic risks are transboundary or cross-sectoral in scope. In light of the aforementioned complexities and uncertainties surrounding systemic risk, the question arises: what constitutes “good” risk handling within modern societies? Renn [27] proposes a risk governance framework consisting of five elements: pre-assessment, risk appraisal, risk characterisation/evaluation, risk management, and risk communication. Pre-assessment deals with framing the risk (early warning and preparation for handling a risk) and identifying and involving relevant actors and stakeholders to capture different perspectives on a risk, its associated opportunities and potential strategies for addressing it. Risk appraisal comprises risk assessment and concern assessment, i.e., assessing the technical and perceived causes and consequences of the risk. Risk characterisation and evaluation includes comparing the outcome of the risk appraisal with specific criteria elaborated by decision-makers, determining the significance and acceptability of a risk, and preparing for decisions. Risk management deals with decisions and implementation of

risk management options. Finally, risk communication is central as a cross-cutting issue that challenges all other risk governance phases. Overall, then, risk governance “includes matters of institutional design, technical methodology, administrative consultation, legislative procedure and political accountability on the part of public bodies, and social or corporate responsibility on the part of private enterprises” [27: p. 364].

In the field of *transition studies*, scholars have explored processes of medium- and long-term transformation from a socio-technical systems perspective, combining narrative analyses with more practical guidelines [28, 29]. This research field focuses on understanding, analysing and encouraging socio-technical change. Against this background, several strands of research have emerged, such as strategic niche management [30, 31], transition management [32–34], and the multi-level perspective (MLP) approach [29, 35, 36]. The latter conceptualizes transitions as an interplay of dynamics between the landscape (macro-level), regime (meso-level), and niches (micro-level). MLP is a sort of heuristic device, or middle-range theory, meant to direct “the analyst’s attention to relevant questions and problems” concerning transitions [37: p. 33]. In contrast, transition management aims to support decision-makers and other actors in making a transition, which is a long term, cross-domain, cross-scale, multi-actor, and multi-domain process. The long-term nature of the process highlights several key aspects. It is crucial to develop strategies to integrate long-term governance and concerns into the realm of “regular” policymaking, as the latter “is generally focused on the short- and mid-term because of political cycles, individual interests, and public pressure” [38: p. 169]. Policymaking itself is complex and uncertain, and clear solutions are sometimes difficult to design [28]. Finally, attention must be paid to “learning, interaction, integration, and experimentation on the level of society (...), as every action or solution will lead to changes in the societal structures, in turn transforming the problem itself” [38: p. 164].

In summary, the literature review concerning long-term governance provides the following key insights: governance research highlights the multitude of actors and institutions that make up modern policy making, yielding in best case to collectively binding decisions. Earth system governance indicates the severity of scales with the global dimension of many environmental problems, and the long-term time horizon, necessitating corresponding institutional regimes and settings. Risk research indicates to the importance of threats confronting societies and offers insights into how to deal with them in modern societies. Finally, transition studies research the process of change and propose tools for understanding and managing complex socio-technical system transformations.

Energy transition as a long-term governance case

The case of the energy transition is a good example of long-term governance, which we will briefly illustrate. The transformation towards a renewable energy system aims to de-fossilize the energy use by 2050 as a climate change mitigation solution pathway. The Paris agreement [39] calls for carbon neutrality by the mid-century. The preferred solution is to change the energy provision from fossil fuels to renewable energies, with policies that apply economic instruments (so-called “carrots”) to encourage investments by private businesses. Replacing the entire power park and adding new systems to better balance energy demand and supply requires long-term investments in new energy technologies, which have monetary payback periods of often 10–20 years. Investors, therefore, call for stable boundary conditions for new technologies. As these technologies are often at the beginning of their development, they need support instruments that make investments competitive. A long-term perspective is also needed for continuous investments that help to run down the learning curve of technologies and bring their prices down.

A first example of long-term decision-making refers to one of the most popular instruments implemented, i.e., the feed-in tariff for solar installations, which provided the investors with a guaranteed long-term (usually 20 years) price for the energy provided. The return on investment should be similar to that of a bank investment over the same period to make it attractive. However, policy outcomes vary between countries. A comparison between Spain and Italy, for instance, shows that revenues were much higher than system costs [40]. This resulted in rapid growth of photovoltaic (PV) installations. In Spain, the installed capacity reached 4GW in 2008, ten times more than the national targets. As a result, by 2009, drastic cuts have been undertaken in the renumeration, bringing investments down to almost zero. In Italy, 3.1 GW were installed in 2010, 4 GW were awaiting connection. If all this capacity had been connected, the 2020 targets would have been almost reached by 2011 [40]. The German tariff was different. It had an annual reduction that lowered the tariff every year. In 2009, costs started to fall faster, which led to a larger difference between costs and renumeration. This caused a large public debate about unfair windfall profits for PV installers, who profited from the money of all electricity customers. This led to a number of extra unscheduled tariff reductions in 2010 and 2011, and later to a scheduled reduction of the tariff every quarter of the year. This learning approach to the feed-in tariff kept the net present value quite close to the actual system costs.

A second example is the development of the wind energy industry. A secondary target of a support regime

is to create new local jobs and industries to compensate for job losses in the fossil industry. An analysis of the evolution of the global wind power industry [41] shows how the development of national markets influences the development of the industry. Markets with stable market conditions are much more likely to develop national industries than markets with unstable conditions, which experienced a much earlier shake-out of companies.

A final example is the ability of different nations to adapt to changing conditions for energy. An analysis by Meckling et al. of the 1973 oil crisis and the impacts of the recent conflicts in the Ukraine identified three groups of nations: “insolation—policy makers are shielded from political opposition; compensation—policy makers ease the burden of adjustment for business and customers; and markets—policy makers step back and markets drive the change” [42]. The first two can create more stable policy regimes, whereas market-based transitions can be much more volatile and subject to price fluctuations.

The case of energy transition shows the long-term approach of solution pathways with its “in-between” social, economic and environmental consequences and the corresponding need to continuously adapt and adjust. This leads us to elaborate the scope and definition of long-term governance.

The scope of long-term governance and its research

Long-term governance requires careful attention to issues of temporality, to the management of uncertainty, and to the interplay between the short and the long term [43]. Urgent and integrated policy responses and long-term governance efforts are needed that take into account two major problems: first, as a consequence of the system complexity and the long time-lags between policy action and effort, these processes of social–ecological change are characterized by a profound level of uncertainty [44–46]. Second, while it is clear that knowledge is required to formulate such responses, it is less clear how to produce and mobilize this knowledge effectively and legitimately [47]. This latter aspect not only includes issues at the science–policy interface, but also reflects the question of how to integrate the interests of future generations into policy-making processes [48]. Since long-term problems can last for generations, the time horizons for addressing them must exceed the regular governmental cycles of elections, decision making, planning, and budgeting [49]. Political actors are influenced by time constraints due to the temporary nature of democratic rules, and these short time horizons may provide incentives to focus on immediate electoral gains, often at the expense of responsible long-term governance [50]. Governments in particular can find it difficult to develop and execute long-term strategies due to their highly politicized and

rule-bound nature [51, 52]. Moreover, the political incentive structure may be affected by discounting and time inconsistency, and long time-lags between policy effort and effect can lead to extreme temporal asymmetry in participation and political power, as the concerns and preferences of important future stakeholders have no bearing on current political decisions [44].

Against this background, we define long-term governance as the political handling and policy-making to adequately cope with enduring problems that spans over a long period of time—i.e., as a rule of thumb, at least one generation (approximately 25 years). Governance is used here in a broad sense according to Meuleman & Veld [53] and encompasses the totality of interactions between the government, other public bodies, the private sector and civil society, aimed at solving societal problems or creating societal opportunities to address the complexity of the problem. In our view, research on long-term governance addresses analytical, normative and transformative issues:

- Analytically, it yields to better understand the mechanisms, challenges, and critical success factors of long-term problem-solving processes.
- Normatively, it aims at long-term governance decision-making that addresses the policy problem in the best and most beneficial way for society.
- And transformatively, it considers change as a key constituent to deal with in long-term governance approaches.

The governance process endures over time for two main reasons: the first characteristic of any governance process addressing long-term problems (“pathway”) is complexity and uncertainty, which determines its persistence: not only is there no single right solution, but any pathway trying to solve it needs to address many different known and emerging, partially intertwined technical, economic and social issues over time, in particular in the phase of policy formation within the policy cycle. The second characteristic is that at best there is only consensus on general goals, such as the decarbonization of the energy system by the mid-century in Europe. What a decarbonized energy system will look like and which specific solution-pathway to this target has to be selected must be negotiated contextually and may need to be readjusted according to societal preferences, evolving knowledge and other external influences.

Ideally, we understand long-term governance as the most forward-looking and adequate political handling of large-scale, target-oriented change processes. Long-term governance addresses a policy problem through reflexive, anticipatory and adaptive action, considering

its uncertain, complex and ambiguous nature due to the unusually long temporal relationship between problem identification, coping interventions, and intended and unanticipated effects. Addressing uncertainty and the need for constant negotiation and adaptation requires long-term, integrated, comprehensive, and iterative learning efforts that combine the technical with the organizational, social and economic dimensions.

Main text

Elaborating a long-term governance framework

Long-term governance is a fuzzy and complex topic. Thus, based on further literature insights, we developed an analytical framework for long-term governance to gain a better understanding and facilitate further research. A general framework helps to identify the crucial elements of an object and their relation, and organizes diagnostic, descriptive and prescriptive inquiry [54]. The framework comprises the following building blocks:

- The “*environment*” details the policy-making arena of long-term governance
- The “*policy issues*” elaborate on problems to be dealt with by long-term governance
- The “*key challenges and driving force*” reveal mechanisms of long-term governance
- The “*key strategies*” identify promising approaches to good long-term governance
- The “*policy cycle*” asks about long-term governance impacts on policy phases

The long-term governance environment

The governance environment refers to the political arena in which government, other public bodies, the private sector, and civil society interact to solve societal problems or create societal opportunities [53]. Thus, the governance environment comprises a relation between: (1) a governing system and (2) systems to be governed (including the institutional setup of the governing system) [55, 56].

The systems to be governed and long-term governance

The systems to be governed relate to several sub-systems (polity, economy, society, science) with their functional specifications and mutual interactions, which make up social systems in modern societies [57, 58]. Each sub-system has its own rationale for achieving effectiveness, efficiency, legitimacy, and social cohesion. Long-term governance issues, such as climate change, emerging technologies, or biodiversity, etc., touch upon several systems of organized complexity. These systems are dynamic, evolving and self-organizing, and respond

with unknown feedback loops and cascading effects [56]. Thus, it is extremely difficult to foresee and forecast social system behavior and assess policy intervention effects and outcomes—in particular with a long-term future perspective. There will be no clear ex-ante picture of how social systems will evolve and simple policy planning and intervention activities certainly will not yield the intended outcome [59, 60]. In addition, these sub-systems largely operate in a self-organizing mode, in a highly complex intra- and inter-system interaction, so that interventions may have very different outcomes than expected.

What scholars empirically observed [61] is that decision-making in modern societies has become increasingly complex due to structural and procedural changes within and across existing sub-systems and society as a whole: globalization, increased international cooperation and multilateralism (such as the European Union), societal changes, including the increased citizen engagement and the rise of non-governmental organizations (NGOs), the changing roles of the private sector and an increasing complexity of policy issues. All this makes it difficult to make decisions with confidence and legitimacy. The interfaces between the sub-systems and policy-making are, therefore, crucial.

The governing system and long-term governance

Against this background, the governing system has been characterized as shifting from a traditionally hierarchical to a more co-operative form of governing, i.e., from government to governance [21]. For a long-term governance approach, two aspects are crucial—the impact of a governance style and the range of policy interventions and instruments.

A robust long-term governance approach builds on existing polity, politics, and policy configurations. Countries and nation-states have uniquely developed their specific policy regimes based on historical developments and their political cultural alignments. Renn [62], for example, differentiates four governance approaches—adversarial, fiduciary, consensual, and corporatist—as defining patterns of interaction between science and politics, and policy-making. In the literature, it is often argued that democracies are not well equipped to implement long-term policies that impose costs on the present for the benefit of future generations. In this sense, long-term governance brings the “when” into policy-making as it can introduce a strong temporal delay between cost and benefit [63, 64]. Research focusing on the effect of different forms of democratic institutions on a democracy’s ability to consider long-term aspects in political decision-making suggests that democratic myopia is more

prevalent in some forms of democracy than in others. Caluwaerts and Vermassen [65: p. 191] show in a comparative study that “democracies with coalition governments, proportional electoral systems, multiparty systems and high levels of public participation among diverse societal groups, are more future-regarding than those built on majoritarian foundations.” Furthermore, if policy-makers can take decisions that have long-term benefits, but short-term costs, without being made personally responsible and having to fear not being reelected (“insulation”), future-regarding decision-making is more likely to take place. The same is true if a country can offer compensation for costs imposed on individuals and industries, e.g., due to the energy transition [42].

Irrespective of these general democratic configurations that encourage or discourage future-oriented decision-making, some countries choose to create institutions whose explicit task is to bring future-oriented thinking into the decision-making process, such as parliamentary committees or offices for future generations. There are several success factors for the working of such institutions: a certain degree of institutional independence rooted in the political system, the need to foster deliberation and diversity, and the need to be empowered to set agendas and influence political decision-making [66].

The toolbox of policy instruments and political steering are another important component of long-term governance. The debate on political steering started off when the failure of the planning euphoria of the late 1960s became apparent. The shift from planning euphoria to control skepticism largely paved the way for the governance debate. The scope of the exercise of political power was thus expanded from command and control towards more non-hierarchical forms of political steering. Direct political steering with command and control via sticks, indirect steering as incentive-based via carrots, pervasive and information-based steering via sermons, and—in addition—so-called contextual control (e.g., nudging), structural control and societal self-regulation mark the spectrum of governance intervention strategies. The control spectrum of governance thus covers the extremes from hard to soft steering approaches. In the context of long-term governance, the aforementioned spectrum can be employed if the chosen approach enjoys a high degree of legitimacy. Otherwise, its long-term implementation may be jeopardized [65].

While traditional policy instruments of carrots, sticks, and sermons are familiar [67], soft and indirect control approaches are less known. Göhler [68] detailed three types of soft control that relate to indirect and contextual steering approaches: control through discursive

practices; control through questions and arguments; and control through symbols.

Control through discursive practices refers to the socially accepted content of meaning and can be deduced from Michel Foucault’s work [69, 70]. These discursive practices structure, determine and generate social discursive debates and, consequently, guide subsequent actions. Control through discursive practices can set in motion a variety of mechanisms to act on a specific context without the aid of hierarchies. An example of this type of steering is the way specific events are categorized (e.g., the corona pandemic in Germany with strict lockdown policies and Sweden with loose ones), leading to different policy actions. Control through questions and arguments focuses on the direct influence on the interlocutors and not on the framework conditions. Questions and arguments induce mechanisms of substantive justification. Justification pressure, although neither coercion nor command, leads to an influence on the addressees and thus enables soft control. In the German parliamentary policy-making process, there are several questioning instruments (e.g., major and minor interpellation, written question, etc.) which initiate mechanisms of questioning, argumentation, justification and subsequently a corridor of courses of action, since policy action needs to be in line with reasoning [71]. Finally, soft control via symbols refers to condensing meaning and content to a signifier which leaves considerable room for interpretation. Symbols can be used as intentional soft control in case they allude to common values and, therefore, generate social resonance which structures action orientation. Many actors in social-political debates, such as NGOs, political parties, business groups, etc., use symbol control mechanisms to find legitimacy and support within society [68]. An illustrative example is the picture of a polar bear clinging on melting ice as a symbol of rapid climate change.

Long-term governance policy issues

Not all societal problems require a long-term governance handling, but some issues do. What are the dividing lines that differentiate long-term governance issues from others? Governance requires something to be acted upon—that is, something that is perceived as a public problem (or opportunity) and subsequently enters successfully the political agenda and then the decision-making process [72]. Indeed, a policy problem is defined “as a condition or situation that produces needs or dissatisfaction among people for which relief or redress by governmental action is sought” [73: p. 81]. While early research directed the problem definition process solely to objective facts, current scholars emphasize that both individual perceptions and objective facts are equally important in making

a condition “a problem” [74]. The goal of policy problem handling is to prevent serious harm to humans and the environment, or to create social opportunities, for instance by improving people’s living conditions compared to the status-quo. Once a problem is “identified”, a process of discussion and eventual placement on the political agenda follows. This is in line with Kingdom’s multiple streams framework, which posits that issues emerge through a confluence of problems, policies, and politics [72]. However, this process is deeply embedded in power dynamics and social negotiations that shape how problems are politically framed and recognized [75].

The long-term as persistency of problems and/or solutions

Temporal persistence takes “time periods” as a defining attribute for long-term governance issues. Thus, the policy issue (problem/opportunity) and/or the corresponding policy solutions are enduring over longer time periods. The long-term here is commonly defined against short-term horizons (e.g., election cycles) as a generation (about 25 years), several decades up to a hundred or even more years, depending on the specific issue. The long time periods can be caused by various circumstances, either related to the source and/or the solution of the issue, and its target orientation as either benefit-seeking or damage-avoidance.

The *policy issues’ target orientation* area can be differentiated between a focus towards damage-avoidance or benefit-seeking. Damage-avoidance takes a risk perspective, identifying severe threats that need to be addressed by policy-making. The main feature is the potential of consequences that harm what people value. The long-term persistence of an issue can be caused by large uncertainties about the risk consequences; by different values associated with the risk, resulting in different assessments of target setting and need for action; and by policy solutions that, for instance, take a long time to be effective. The creation of opportunities from a benefit-seeking perspective often targets social, health or employment policy areas. The long-term persistence for both types of target orientation relates to a continuous discrepancy between target-setting and its non-achievement.

The *policy issues’ source and solution* area address the nature of the problem source and the solutions being considered. Both can form the basis of long-term persistence. On the source side, for instance, we may be confronted with risks that cause triggers that cannot be eliminated by risk management policies. Consequently, these risks continue to pose a threat and require a more “permanent” policy action. The complexity and uncertainty of the risk source, with its cause–impact relationships, intervening variables, delayed effects and unknown side-effects, may indeed constitute a long-term

governance issue. However, the implementation of policy solutions can also result in long-term persistence. On one hand, differences in social values regarding the risks and benefits of potential pathways may complicate the design and selection of adequate policy solutions [76–78]. Thus, decision-making is a time-consuming process that also necessitates windows of opportunities for certain policies to come into force [79]. On the other hand, solution policies can be comprehensive, complex and based on each other and require a long-term perspective [80–82].

The two aspects of long-term governance policy issues—target orientation, and source-solution—are combined in Fig. 1 as a matrix to illustrate long-term governance issues.

In the following, we provide some examples of long-term governance issues from the case of energy transition.

A *source–damage* example relates to specific socio-technical systems that have persistent negative consequences that may require long-term governance. These issues may stem from legacies of prior, but still lasting, natural developments or human activities. Most prominent in this field are long-lasting technologies and large-scale infrastructures that have been built in the past, but still need political action to guarantee their safety [7, 83]. Czada [60] pointed out four aspects of technologies becoming long-term issues: implementation may cause irreversible changes to society and the environment. The termination of control of the technical project would result in disadvantages and damage to society and the environment. The possibility of conclusively regulating the technology at present is limited, in that it is uncertain how the overall socio-technical system will change in the long run as a result of the implementation and operation of the technical facility with its infrastructure elements. The goal of institutionalized control by a governance network is the preservation of the common good precisely over longer periods of time. Examples of source-damage

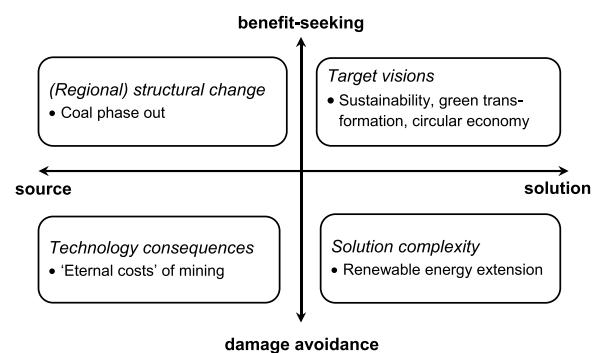


Fig. 1 Matrix of long-term governance issues along target orientation and problem coping. Source: own elaboration

issues are the so-called eternal costs related to underground mining. In the Ruhr area of Germany, the so called “Ewigkeitskosten” are the eternal costs related to the drainage of land submerged by coal mining, which involves the continuous and eternal pumping of water out of the area to keep the land artificially dry and prevent it from sinking further. Other examples of long-term issues requiring long-term safety maintenance are nuclear waste disposal, energy and transport infrastructure, dams and levees. In these cases, policy action is needed to ensure the management and maintenance of long-term safety to prevent serious damage.

A *solution-damage* case refers to complex solution packages that cope with the problem, but need considerable time to be designed, implemented, or to demonstrate their efficacy. Many policy solutions tackling severe environmental risks fall into this area. Climate change, overexploitation of natural resources, environmental pollution, etc., refer to economic activities and their impacts on the planet that jeopardize the overall balance of the Earth system by crossing the planetary boundaries. Coping with these threats requires policy solutions that fundamentally tackle the sources of the threats—but take considerable amounts of time to materialize due to policy implementation constraints [84, 85]. An example of a time-consuming implementation is the decarbonization of the energy system through the expansion of renewable energy solutions. A key policy response to climate change is to decouple energy (production and consumption) from CO₂ emissions by substituting fossil fuels with renewable energy (e.g., solar and wind power). However, the mere size and scale of the transformation requires considerable amount of time, as several technologies along the energy production, infrastructure and consumption chain need to be replaced. Complex policy packages and mixes are, therefore, needed, for instance to help install onshore and offshore wind and photovoltaic power, to encourage the expansion of energy grids and to stimulate adequate energy use devices (heat pump, electric car). The timeline for Germany’s energy transition policy targets, for instance, is a 60% share of renewables in energy consumption by 2045 [86]. It should also be acknowledged that the implementation of such energy transition policies is often met with controversy and resistance from various stakeholders, which can lengthen their enactment [87, 88]. This is due, for example, to differing social values, economic concerns, and other political dynamics.

A *source-benefit* case relates to the improvement of living conditions, typically in the field of social, health or employment policy. Empirical socio-economic data and the forecasting of future trends can be used as a basis for early warning and raising awareness of a problem.

Specific examples include the ageing populations, skills shortages, and public debt, which are among the most significant social problems shared by advanced industrialized countries [64]. The countries of the global South are also characterized by long-term issues of improving living conditions, such as fighting poverty, providing sufficient food and drinking water, safeguarding jobs and workers’ rights, etc. Another illustrative example in the field of energy is regional structural change policies as a transition away from coal phase out in Germany. The legal basis for this phase out is the Act to Reduce and End Coal-Fired Power Generation (KVBG), adopted in July 2020. This legislation foresees coal-fired power generation to be gradually reduced and phased out by the end of 2038 at the latest. As an indirect, but intended consequence, lignite coal mining will also be phased out. A major policy effort is currently underway with the objective of implementing benefit-seeking measures designed to facilitate the transition process in the affected regions. These measures are intended to address both the job losses and to support the structural changes that are necessary in the coal mining regions to establish future-oriented business and industry.

A *solution-benefit* case refers to specific far reaching target visions of “better futures” that might trigger concrete policies. Visions of change usually comprise rather normative concepts and guiding principles that might aim at fundamentally changing the way we live. One example are debates on sustainability and transitions with its political embedding and operationalization within the sustainable development goals (SDGs), i.e., grand challenges whose solutions require more radical and disruptive changes and thus unfold over a long period of time [88–90]. Value orientation towards inter- and intragenerational justice in sustainability is fundamentally based on time. Further examples of far reaching solution-benefit target visions are, for instance, those based on the concepts of bioeconomy and circular economy [91, 92], green transformation [93], smart cities [94], or growth-critical concepts, such as degrowth or post-growth [95].

Key challenges and driving force of long-term governance
This section identifies, based on the existing literature, the key challenges that undermine long-term governance. In particular, the following are considered: (1) the openness of the future; (2) the intertemporal divide; (3) the presentist bias, a—and, as a key driving force (4) future expectations and narratives that guide societal actions, thereby making long-term governance happen.

The openness of the future challenge

A long-term perspective encompasses a governance approach that looks far into the future. At its core,

however, future developments are open, uncertain, and difficult to predict. The future openness is due to the existence of deep uncertainty, described as a situation “where it is difficult to agree on the relationships between the key driving forces of change in the long-term or on the probability distributions used to represent uncertainty about those factors” [96: p. 1]. Adaptive governance approaches are, therefore, considered to be suitable to consider deep uncertainty [97]. It is inevitable that both positive and negative surprises will occur in the short and long-term. This is due to a number of factors. The openness of the future is contingent upon the stochastic nature of cause-and-effect relationships. The envisioned development of social systems relies on stochastic relationships comprising many variables that interact mutually and influence each other. For example, interactions relate to the individual and/or collective contingency of decisions. In addition, depending on how decisions were made, they influence future decisions. Another example is natural events, which are impossible to point predict. The risk of an earthquake or a volcanic eruption can be estimated as high, but it is not possible to point predict these events far in advance. Knowledge deficits are another major reason for uncertain futures. Uncertainty ultimately arises, because there is a “limitedness or even absence of scientific knowledge (data, information) that makes it difficult to exactly assess the probability and possible outcomes of undesired effects” [61]: p. 234]. When facing complex problems and systems, human knowledge is always incomplete and selective about assumptions, assertions, and predictions [27, 98, 99], and it is, therefore, difficult to assign probabilities, e.g., when defining risks, even though some forms of judgments are still possible [100]. Uncertainty thus manifests itself on the time scale of long-term governance, with difficulties in forecasting its concrete outcome within the variety of possible futures [101]. As such, the issue of uncertainty remains a fundamental hurdle for rational decision making, since “future states of the world are not predictable because of the complexity of situations in which decisions are made; unforeseeable effects of interactions; genuine novelty brought about by unpredictable innovations; and the contingency of other actors’ choices” [102]: p. 8].

The intertemporal divide challenge

A key characteristic of long-term governance is its intertemporal divide between the present, the short-term, and the long-term, in short: the temporalities. There are tight linkages between the present and the futures. One aspect of the intertemporal divide challenge is the temporal fragmentation both of problems and solutions. Issues such as climate change lead to both acute crises

and enduring creeping risks, with different policy action needed. Enacting change to tackle these issues is, therefore, also a complex and uncertain process [103, 104]. The occurrence of weather extremes, such as forest fires, intensive flooding, and extreme droughts, call for urgent action, which, however, might not tackle the causing effects. Thus, policy action addressing creeping risks with possible future negative outcomes is simultaneously needed. Solutionwise there is also a high degree of fragmentation. On one hand, there is often a temporal divide between costs and benefits. On the other hand, large-scale problems require radical solutions, often involving complex and time-dependent policy packages with intermediate targets. The energy transition, for example, is being tackled via complex policy packages developing over time: feed-in tariffs, off-shore wind parks, interim renewable expansion targets, subsidy programs for electric cars, energy storage technologies, system flexibility through sector-coupling, etc., are just very few components of an energy transition policy package. If one considers that policy-making itself is a somehow chaotic and unpredictable process [71, 105, 106], it becomes clear that the intertemporal divide challenge for long-term governance is considerable. It requires both being open and adaptive, as well as closing down contingency and trying to fix long-term goals, at least for guidance [104]. Another issue is the difficulty of engaging the public in long-term governance, especially when the benefits of policies are not immediately apparent [107]. Sustaining public engagement on these types of issues requires continuous efforts.

The presentist bias challenge

One of the challenges of long-term governance is the already mentioned myopia in policy-making, especially with regard to the so-called presentist bias both within the systems to be governed and the governing system [64, 108]. There are several indications strengthening the presentist bias. Jacobs [64] identified several presentist bias factors. The first is the paucity of information about longer-term outcomes. Indeed, there is a notable asymmetry in the information available, with much more data on past and present events than on future ones. As a result, voters tend to prioritize current issues over future concerns when communicating with policy-makers [109]. The second is the fragility of long-term political commitments. This refers to the fact that policies with long-term benefits often come with short-term costs. Present constituents often challenge such political commitments, because these costs are borne unequally across generations and social groups (intergenerational and distributional issues) [110]. The third challenge relates to the power difference among affected stakeholders, in

that organized groups are both highly attentive to policy consequences that affect them and are able to mobilize against policies that go against their interests [64].

The institutional setup of democracies favors short-termism (e.g., parliamentary terms, short election cycles, budgetary and fiscal policy). The institutional arrangements developed according to past and present problem-solving produces siloed policies. Silos originate from the way institutions have historically developed and are structured with departments for health, the environment, the economy, etc. [56]. What is needed for coping with future issues, instead, is policy coherence and cross-sectoral public bodies.

The presentist bias challenge is also backed by ambiguity. Ambiguity refers to the variability of interpretations based on identical observations or data assessments, and relates to both the target and possible outcomes [100, 104]. Indeed, social groups usually hold different values and meanings towards certain problems and their solutions [100, 111], and this influences the way they judge events, set priorities, calculate risks, and propose solutions. Key differences in interpretations may arise, for example, when trying to understand what a problem means for humanity and the environment. Ambiguity leans towards the present due to the impact of mental models and heuristics. Social-psychological research revealed that human attitudes and choices depend on simplified heuristics (i.e., availability heuristic) [112–114]. These intuitive heuristics are presence-oriented and correspond with satisfying rather than optimizing strategies [27]. This has a major impact on the definition of risks, for example, as Stirling [100: p. 310] states, “where there is ambiguity, reduction to a single ‘sound scientific’ picture of risk is also neither rigorous nor rational”. Indeed, goals such as “fighting climate change” should be understood as a process along which participants collectively define “what” should be fought and “how”.

Future expectations and narratives as long-term governance driving force

Having identified the challenges that hamper long-term governance, a crucial question remains: what is the driving force that, despite the aforementioned challenges, encourages a long-term governance perspective? In our view, theories of expectations provide compelling arguments for how visions of the future influence the present, that is, how they contribute to long-term processes of policy-making, societal debate and technological developments [75, 115].

We draw here on a book by Jens Beckert [102] on imagined futures, which provides a solid interdisciplinary basis for understanding why the future matters. Beckert argues that images of the future state of the

world or possible courses of action—so-called *imagined futures*—are a fundamental source and motivation for economic decision-making today [102]. Future expectations have the “as if” power: “Expectations under conditions of uncertainty and ascribed symbolic meanings may be seen as a kind of pretending, which creates confidence and provokes actors to act as if the imaginary were the ‘future present’” [102: p. 10]. However, the opening of the “as if” space is not arbitrary and does not open up countless opportunities for action. On the contrary, “Expectations, and stories about the future in general, reduce essential contingency in a non-deterministic sense, by providing blueprints that can be used in action” [116: p. 217; 117]. A key example of future expectations in economics is money and credit, which are the backbone of capitalism. These are based on fictional expectations, because they entail the promise of future value and “belief in their value depends on imaginaries of uncertain future states of the world” [102: p. 128]. In essence, investments represent future visions of anticipated profits. Business investment in plant production facilities for the purpose of providing goods and services is predicated on the expectation that future sales will yield higher returns than the initial investment.

Another object of strong expectations within the capitalist economy is technological innovation. These expectations play a fundamental role in shaping the development and design of new and innovative technologies. Such expectations can be either positive, entailing desired benefits, or negative, expressing concerns about social and cultural decay. These conflicting technological visions often coexist [79], once again demonstrating that the adoption and development of technologies is a political matter [75, 117–120]. The role of expectations in science and technology has been analyzed in detail. Future-oriented abstractions and expectations can be seen to be fundamentally ‘generative’. According to Borup et al. [121: p. 286], “they guide activities, provide structure and legitimization, attract interest and foster investment. They assign roles, clarify duties, offer some shared shape of what to expect and how to prepare for opportunities and risks. Visions drive technical and scientific activity, warranting the production of measurements, calculations, material tests, pilot projects and models”. These manifold impacts of expectations are evident in policy-making, where respective fields of policies (e.g., innovation policy, education policy, competition policy, and environmental policy) are concerned with shaping the socio-technical environment of science and technology. Thus, they constitute a fundamental driving force for long-term governance.

Key strategies for good long-term governance

In light of existing literature, we deduced four strategies for an effective long-term governance: (1) reflexivity, to identify problems and solution-oriented goals; (2) anticipation, futuring, and iteration, to best prepare for change; (3) adaptation, flexibility and robustness, to navigate through change; and (4) deliberation, probing, and learning, to experiment with change.

Reflexivity towards long-term issues, problems and objectives

The concept of reflexive governance [122, 123] builds upon Beck's work on the risk society [7]. It recognizes that "governing activities are entangled in wider societal feedback loops and are partly shaped by the (side-) effects of its own working. It [therefore] incorporates such feedback by opening problem-handling processes for diverse knowledge, values and resources of influence to learn about appropriate problem-definitions, targets and strategies of governance for sustainable development" [124: p. 4]. If reflexive, governance should, therefore, evolve to adapt to the changing environment and the emergence of unexpected consequences caused by governance itself.

The principle of reflexivity can be applied to each step of governance, for example, in relation to the process of problem-definition, setting targets and devising solution strategies. Reflexivity in this sense entails the continuous initiation of problem and solution search processes within both the governing and the governed systems. Early problem identification and the subsequent goal setting are linked to the science–policy–society interface as well as to ethical considerations.

Given the inherent complexity, uncertainty and ambiguity of long-term governance issues, the science–policy–society interface is of crucial importance. It indeed requires a scientific community that is committed to the scope and able to discuss its concerns effectively with society and advise policy-makers on possible solutions [27]. Therefore, long-term governance should be equipped with mechanisms to ensure that policies are not only scientifically sound, but also socially relevant and accepted [75]. Public engagement has indeed a pivotal role in this matter, as it serves to democratize both science and policy, thereby enhancing their accountability [124–126]. To improve the science–policy–society interface, several proposals have been put forth, including the establishment of specialist parliamentary committees dedicated to exploring long-term or future-oriented matters [108] and the enhancement of science–policy ecosystems through the work of interface actors who facilitate long-lasting collaborations between scientists and policy actors [56].

The role of ethics emphasizes the significance of values in long-term governance. This leads to considerations of

both intra- and intergenerational justice. Should action be taken immediately to fulfill the needs of the current generation, or should it be postponed to take adequate responsibility for those who will live in the future? Indeed, long-term governance is essentially about ethical issues of trust, responsibility, and fairness across generations. In the terminology of the political philosopher John Rawls, this could be expressed as follows: development pathway evaluation must be based on beliefs, values, and principles that are shared by all reasonable worldviews and democratic parties in an overlapping consensus [127, 128]. Thus, integrating ethics and value orientation calls for the establishment of future councils and the representation of future generations [129], fostering moral reflection [56]; and ensuring consistency of policy setting with well-established principles of intergenerational justice [108].

Preparing for the change: anticipation, futuring techniques, and iteration

As previously stated, the open future uncertainties represent a major challenge for long-term governance handling. Consequently, it is important to be best prepared for any future developments that may arise acknowledging uncertainty constraints. In this context, anticipatory governance concepts have been developed [130, 131]. Fuerth's anticipatory governance comprises a system of systems with four basic components: a foresight system, a networked system for integrating foresight and the policy process, a feedback system to gauge performance and also to manage "institutional" knowledge, and an open-minded institutional culture [130]. The concept has been applied to issues, such as climate change, sustainability, and socio-ecological systems resilience [132].

It becomes obvious that the science–policy–society interface is again essential here as an anticipatory governance arena. On one hand, science and society can provide possible, probable, and/or socially acceptable pathways and options for long-term governance issues, and on the other, policy makers need support for debating, deciding and implementing long-term governance. In scientific research, futuring techniques are employed to investigate future developments and specifications. Among the most prominent methods used are Delphi surveys, computer simulation, scenario analysis, transformation change theories, horizon scanning, cross impact analysis, technology forecasting or backcasting. It is, however, crucial to acknowledge that no single method can guarantee optimal outcomes, given the inherent complexity, uncertainty, and ambiguity of social transformations. The judicious integration of research methods (e.g., direct or indirect coupling)—or, in instances where this is not feasible, the integration of

results from individual disciplinary (interdisciplinarity)—is important in addressing these complexities [133, 134]. Finally, transdisciplinary research is an umbrella concept for integrated research and science which involves society. It includes not only scientific actors but also representatives of politics, the private sector and civil society, since these groups can provide special orientation and action knowledge that helps to promote the transition. Considering several actors via participation and involvement aims at enhancing agency towards target-oriented transformations.

In the realm of politics, several requirements backing anticipatory governance have been delineated [130]. These include the incorporation of anticipation and futuring techniques into institutions, rules, and decision-making processes to reduce risks and enhance the capacity to respond to events at an early stage of their development. Anticipation should be present at every governance scale, from the communal to the global.

Iteration of anticipation and futuring exercises is a fundamental success factor for long-term governance. Regardless of the methodology employed, the resulting projections are inevitably imperfect approximations of how the future will unfold. Within complex social system development, for example, the considered starting conditions may rapidly change. The global financial crisis of 2008, the global COVID-19 pandemic of 2020, and Russia's invasion of Ukraine have all had a significant impact on the world's "landscape". It is imperative that these changes are considered on an ongoing basis to inform future anticipation efforts. It is a continuous effort for science, politics, and society as a whole to repeatedly undertake futuring exercises, with updated consideration of changing starting positions, and to integrate these new anticipatory results into the scope of policy options.

Navigating through the change: adaptation, flexibility, and robustness

Long-term governance runs through considerable periods of time to solve problem issues with high levels of uncertainty, complexity, and ambiguity. What is certain is the fact that the decision-making arena is a hazy environment with ups and downs of change and stability within the systems to be governed causing feedback loops to the governing system. A key success factor for long-term governance handling is to keep up capacity for action, options for action, and power for action—in short: to keep up agency. However, agency must be understood across the full spectrum from hard to soft steering approaches.

The term 'navigation' [135–137] is employed here to describe effective long-term governance agency, as it encompasses the "art of steering", which originated in

nautical science and involves the determination of the "most optimal" route to a desired destination, taking into account the current position and the most efficient path to the destination. Thus, navigating through the change with agency necessitates rightly interpreting the changing environment and making appropriate decisions towards long-term problem solution.

Adaptation, flexibility, and robustness have been identified as key elements of successfully navigating through the change. Adaptive governance indicates a way of governing that allows flexibility to find best tailor-made solutions, and—by doing so—contributes to robustness and resilience of efficient and effective problem handling. Several adaptive governance requirements have been outlined [138], namely: provide necessary information, deal with conflict, induce compliance with rules, provide physical, technical, and institutional infrastructure, and encourage adaptation and change. Adaptive governance has been further researched within the broader social context that enable ecosystem-based management [139], towards institutional adaptation [140], and towards double crisis (acute and creeping) management [141]. The latter emphasized adaptation by designing alternative response strategies and allowing for flexibility to switch paths. That includes cyclical adaptation which involves iterative and continuous cycles of trying, monitoring and adjusting or shifting between policies with the aim of leveraging temporary solutions, feedback cycles, and bricolage to work towards robust multi-functional solutions [141].

Experimenting with the change: deliberation, probing, and learning

This leads to the last fundamental key element—that is experimenting with the change by deliberation, probing and learning. Deliberation and involvement are means to include diverse viewpoints in the governance process to gain a richer understanding of the affected system, provide legitimacy as a necessary governance resource, and enhance the steering toolbox with experimenting along the full spectrum from direct to indirect and contextual governance approaches as laid out above on the steering toolbox of the governing system [142, 143]. By dealing with the problem in their ways, different actors contribute to problem definition and solution [125, 144]. The types of contributions can take on very different forms. For example, in policy-making, creating and maintaining vigilance, offering knowledge, taking care of local interests or fulfilling the function of creating a system of checks-and-balances [145, 146]. Last but not least, long-term problem solving—as for instance with the energy transition—cannot be evaluated solely in terms of technical and economic feasibility. An equally important fact

is the social approval of the decisions associated with the structural transformation, which can be expressed through active participation supporting the change process (e.g., through buying efficient appliances, installing solar energy on their rooftops). The envisaged energy turnaround will hardly be implemented without the approval and engagement of the population, as the reassurance from the citizenry in a pluralistic–democratic society is of central importance.

Experimenting is also most relevant for probing policy action and instruments, and their time adequate implementation. Thus, long-term governance arrangements should combine strategically built (top-down) and emerging (bottom-up) actions as a matter of continuity and flexibility, and probe new arrangements in protected areas [147]. There are several examples for probing environments: one refers to setting smart political framework conditions via, for instance, the so-called regulatory sandboxes and experimentation clause, which allows for innovation through temporally suspending formal regulation in well-defined areas to innovate in specific fields, such as mobility or public administration. Another refers to living labs and real-world laboratories with possibilities to carry out concrete transformation experiments in local settings. The idea here is that researchers conduct interventions in the sense of “living lab experiments” to learn about social dynamics and processes. Co-design, co-production and co-evaluation are essential features of a living lab process [148].

These experiments shall contribute to learning processes as an essential part of long-term governance with their institutional context-conditions need to be understood and considered. Learning in such contexts can take on different forms, such as, for example, instrumental learning, political learning or implementation learning [149]. It is important to keep in mind that learning processes do not necessarily lead to changes in policies. Rather, policy changes also depend, for example, on power relations, vested interests or available resources and the way knowledge is discursively created [149]. From the point of view of institutional psychology, a learning environment that entails both the relevant policies and the institutions involved requires being open about mistakes and establishing measures that welcome the reporting of mistakes. This makes it more likely that counter-measures can be taken to possible maldevelopments that might threaten the envisioned aim of the long-term governance process [150].

Long-term governance and the policy-making cycle

We understand long-term governance at its core as a reflexive policy-making process to address significant enduring and persistent problems within a

decision-making arena based on strategies to best prepare, navigate, and experiment with the changing environment. Public policy-making has been described as a cycle (or process) composed of iterative phases [71, 73, 151–153]. Therefore, we build on the existing literature to start delineating a heuristic long-term policy-making framework and discuss our conceptual understanding of long-term governance in the light of the various stages of the policy-making process. We differentiate the phases of: (1) policy formation, (2) policy adoption and implementation, and (3) policy impact, and re-formulation. In the following, we will discuss each phase from the angle of long-term governance.

Policy formation: problems, agendas, and options

Research has identified several necessary factors for problems to enter the policy cycle and become a public problem. That is, problems that produce needs or dissatisfaction among people, affect a substantial number of people with broad impact, and thus are appropriate to seek governmental remedies [73]. Long-term governance issues are—as identified above—persistent long-term issues dealing with either a benefit seeking or damage avoidance focus attached to the source–solution axis. This poses different requirements to “good” long-term governance handling.

First, screening and identifying possible threats and risks as early as possible is needed. Early warning mechanisms established at the science–policy interface are required to screen and identify possible threats on the science side and stimulate governance agency to push forward a consistent political agenda.

Second, good timing for defying agenda setting rationales and cycles is necessary for sound long-term governance. Since some long-term problems may persist for generations, addressing these issues needs a governance architecture that span beyond the regular governmental cycles of rather short-term elections, decision making, planning, and budgeting. Adopting a longer-term horizon and addressing the needs of future generations might be challenging for democratic institutions, especially when political leaders must be accountable to their current constituents [107]. Even with long-term policies in place, time inconsistency due to the incongruity between cost/benefit considerations may result in incentives to abandon or defect from these policies in favor of short-term gains [44, 154].

Third, consistency and continuous handling of incremental long-term issues are needed across the turbulences and weak predictability of the policy-making processes. Establishing the necessary institutional environments, setting clear targets and evaluation criteria, and providing sufficient resources to deal successfully

with, for instance, long-term infrastructure management, are core parliamentarian and administrative tasks. That includes to invest resources in updating, improving or reusing the technological environment, guarantee high-level education and provision of maintenance staff and flexible management concepts, and provide strong anticipation skills to pre-evaluate changing conditions of infrastructure embedment.

Policy formulation becomes relevant provided a long-term policy problem was identified and successfully entered the agenda setting phase [71], seeking relief through policy-makers and governmental action. What comes next, is to identify policy solutions that will cope with the problem. We introduce the term “pathway” here as a conceptual approach which in our view becomes relevant for long-term governance issues [155, 156]. Policy pathways link the problem with the solution and may entail several principal solution options. The pathway approach is understood as planning tool for governance, as pathways frame, channel, and narrow the scope of policy options and alternatives—and thus work as a fictional future expectation. When it comes to long-term governance issues, it is necessary to consider the following aspects, which greatly influence the use of pathways as governance tools.

First, goal and target setting for long-term governance issues is essential. Before it is possible to design concrete policy options, there is a need to specify long-term targets for an envisaged problem solving. Goal and target setting are search processes involving several actors from science, policy-makers, stakeholders and the public at large, where appropriate. Target specification refers to linking the identified problem with plausible and convincing solution through a target-oriented pathway idea. This means that the problem-solving final status needs to be specified somehow. To provide examples, in the context of climate change, target specification entails, for instance, limiting the global average temperature rise to well below 2 °C above pre-industrial levels. In the field of nuclear disposal, instead, the final target can be defined as ensuring the permanent protection of humankind and the environment from ionizing radiation and other harmful effects of such waste for future generations.

Second, knowledge and transparency of pathway multitudes are essential. As a general rule, there exist several solution-oriented pathways to cope with public problems. A core activity of policy-making is to identify, specify, and select pathways for further governance handling. Pathway identification is, again, a result of close cooperation at the science–policy interface and participatory involvement and societal deliberation. To give some illustrating examples, in the case of climate protection, one could think of two fundamental problem-solving

pathways, that is a pathway of reducing greenhouse gases by substituting fossils fuels, and a pathway of geoengineering activities. The former CO₂-reduction pathway includes solutions like fast phasing-out of fossil fuels, extension of renewable energies, and substitution of fossil energy based towards renewable energy-based energy consuming devices (i.e., oil heating vs. heat pump). The latter pathway of geoengineering comprises a set of activities in the two fields of carbon dioxide removal (CDR) and solar radiation management (SRM), which means the introduction of new (experimental) technologies in our societies. As can be seen, the two pathways follow distinct roads towards problem-solving and include a high level of complexity, uncertainty and ambiguity.

Policy adoption and implementation: policy packaging and incrementalism for change

Policy-making is in its core a decision-making process of responsible persons or bodies to select and decide among alternative policy options to enforce selected target-oriented pathways. Several theories on the process of policy-making exist, such as the rational–comprehensive theory (going back to Auguste Comte), the “incrementalism” introduced by Lindbloom [157] as muddling through theory, or the so-called mixed-scanning approach [158], which combines rationale high-order with incremental low-order decisions. The term “scanning” particularly refers to the search, collection, processing, and evaluation of information, as well as to the drawing of conclusions, to serve decision-making processes [159]. Among the relevant individual and collective decision criteria for policy-making, values, party affiliation, constituency interests, public opinion, deference, and decision rules should be mentioned [73]. Decision-making also includes working out detailed policy options that promise to solve public problems. In a wider governance sense, long-term agency should comprise the full spectrum from hard to soft steering approaches, including contextual and indirect control attempts. Against that background, we see the following major aspects for long-term governance.

First, incremental planning for change means a step-wise approach of detailed implementation action. Once long-term objectives, strategic plans and policy options are selected, the next step is to translate them into short-term plans and budgets [160, 161]. This involves developing an implementation plan, allocating necessary resources, and assigning responsibilities to relevant government agencies or stakeholders. Clear timelines, monitoring mechanisms, and performance indicators should be established to track progress and ensure accountability. However, the implementation of this ideal-type approach poses several challenges, particularly in relation to the role of distributed agency. On one hand, it

is crucial to deliver a strategic direction [88]; and on the other, it can lead to scattered activities. Long-term policies and strategies must also align with the existing routines, budgets and practices within the public sector, underscoring the need for seamless integration of these strategies into organizational processes [161].

Second, integrated policy packaging learning needs to be implemented. Long-term governance issues normally require complex, multilevel policy action on several scales (time, space etc.), to achieve a stepwise target-oriented transformation based on interim feedback loops through policy learning. Coping with climate change, for instance, calls for a fundamental socio-technical regime shift that cannot be reached via single policies. What is needed are comprehensive, decentralized, and integrated policy packages that challenge the prevailing regime and thus pave the way for radical transformation. At a practical level, some strategies can be pursued to mitigate these issues. For example, ensure that long-term values and goals are embedded in policies across different sectors; encourage cross-sectoral coordination to address complex challenges that require integrated solutions; and embed long-term thinking and evaluation into the policy-making process. This may entail establishing dedicated units or bodies responsible for monitoring and assessing the long-term impacts of policies, ensuring ongoing evaluation and adjustment of strategies if needed. In addition, learning environments should be created that encompass the full spectrum of the policy toolbox steering activities comprising both top-down and bottom-up approaches that experiment with the change.

Policy impact and re-formulation: future interest and solution pathway monitoring

Long-term governance is a purposeful political intervention triggered by the perception of a problem that could severely affect our societies over the long run. Given the fundamental and systemic nature of the change to be reached, it cannot be expected that the process will unfold in a linear and rational manner. Thus, an accompanying evaluation and monitoring process is necessary to stimulate redesign, reformulation and subsequent decision-making when appropriate. To understand how to monitor and evaluate long-term governance processes, we will focus on institutional settings, the object of monitoring, and the process of monitoring and reformulation.

First, it is essential that impact evaluation and monitoring are entrusted to one or a set of institutional monitoring bodies, where future interests can be placed. This organization's primary tasks include gathering information for monitoring, and designing corrective measures if the long-term governance process branches off in undesirable directions and if the environment subject to

governance change in a way that might require governance adjustments. This body should ideally be made up of a heterogeneous pool of experts, capable of collecting information and analyzing it, whose composition will most likely change over time, with the emergence of unplanned consequences.

Second, the monitoring object comprises the selection of key indicators and the design of the process itself (e.g., how frequently it should be performed, data collection and data analysis methods, etc.). Useful and valid indicators that work for any long-term governance process are still to be developed and be supplemented with depending reference context of a given long-term governance issue. For example, in the case of deep nuclear disposal geological and safety case minimum requirements are essential, while for the energy transition case, expansion targets for renewable energies are crucial [162]. Furthermore, it is important to keep in mind that variables, classifications, and categories are essentially political in nature: they determine what is seen and valued, and what is obfuscated, hidden, or ignored [163–166]. Therefore, this selection is in its core 'political' and inevitably raises questions of justice, namely, who has the power to decide how a problem should be understood, analyzed, and addressed. From a reflexivity and adaptivity perspective, it should be noted that monitoring variables may change over time due to, for instance, scientific knowledge progress, unexpected emergence of artifacts, agents, and issues, or changes in the composition of the monitoring body. In addition, to meet the reflexivity requirement, a long-term governance monitoring process must be attentive to how power accumulates within the network of actors involved and to how coalitions might steer the overall process to the detriment of potentially more socially sustainable alternatives.

Third, a key feature of long-term governance monitoring is the process of redesign and reformulation with subsequent policy action to ensure an adaptive and reflexive long-term governance process. There are several common dilemmas characterizing these steps. One of such issues is determining the action precedence, i.e., how to order the different challenges and when to prioritize emerging problems. Another dilemma is the 'right' decision-making level to implement the various corrective actions, i.e., the dilemma between centralization and decentralization. While the former favors coordination among planned actions, these could be locally rejected as deemed inapplicable. The latter instead facilitates adaptation to local circumstances (including routines, narratives about the future, and other cultural elements), but could result in a patchwork of actions that could lead to overall inconsistency. A final dilemma concerns the trade-off between a governance structure that gives stability to

the long-term governance process and one that is flexible and responsive to change. At one extreme, excessive structure and bureaucracy slow down the implementation of corrective actions and tend to be insensitive to the demands of change; at the other, governance changing too frequently is incapable of learning and thus of being reflexive.

Conclusions

Climate change, environmental pollution, nuclear waste management, and unsustainable production and consumption all share the common trait of being long-term challenges that often lead to the implementation of novel technological solutions. This long-term nature stems from their complex and uncertain character, their potential for severe consequences, and the demanding problem-solving paths. Indeed, effectively addressing these challenges requires a form of governance that transcends short-sighted visions and short-term mechanisms. Within this paper, we conceptually researched the case of long-term governance based on a comprehensive literature review with the aim to elaborate a generic long-term governance framework. We define long-term governance as the most forward-looking and adequate political handling of large-scale, target oriented change processes. It requires long-term, integrated, comprehensive, and iterative learning efforts that combine the technical dimension with the organizational, social and economic ones. Research on long-term governance relates to three substantial levels, that is: analytically yielding to better understand the mechanisms, challenges, and critical success factors of long-term problem-solving processes and outcomes; normatively aiming at long-term governance decision-making that addresses the policy problem in the best and most beneficial way for society, and transformatively considering change as a key constituent to deal with in long-term governance approaches.

Against this background, we specified long-term governance as a socio-political response to a policy/future problem through reflexive, anticipative and adaptive action, considering its uncertain, complex, and ambiguous nature that results from the unusually long temporal relationship between problem identification, coping interventions, and its intended and unintended effects. Drawing upon diverse sources in governance research, earth system governance, risk research, and transition governance studies, we develop a conceptual meta-framework to establish a robust theoretical foundation for long-term governance. The overall architecture and configuration of the long-term governance conceptual understanding is illustrated in Fig. 2.

The environment of long-term governance is characterized by both the systems to be governed and the

governing system. Decision-making in modern societies has become more and more complex due to structural and procedural shifts within existing subsystems and society at large. Anticipating and assessing social systems behavior and the effects of policy interventions, especially from a long-term viewpoint, proves exceedingly challenging. Conversely, the governing system is transitioning towards a more cooperative form, shifting from government-centric to governance-centric approaches. In a long-term governance framework, two pivotal aspects are the impact of governance styles and the spectrum of policy interventions. While the influence of defining interactions between science, politics, and policy-making on long-term governance remains an open research question, the entire range of control and steering approaches proves indispensable in long-term governance. Long-term governance policy issues are the main subject to deal with, and persistency being their key characteristic. We identified target orientation towards damage avoidance or benefit seeking, and source–solution aspects as the main features of long-term governance issues. Key challenges towards ‘good’ long-term governance were identified as open future, temporal divide and presentist bias challenges based on matters of complexity, uncertainty, and ambiguity in the area of knowledge constraints, institutional settings, subjective perceptions, power relations, and plural interests. A key driving force, however, is the fact that futures matter in present attitudes and decision-making alike with the role of future fictional expectations being crucial. Against these contextual attributes of long-term governance, we identified four key strategies to best cope with these policy issues, that is, strengthen reflexivity towards long-term issues, problems and objectives; preparing for the change via anticipation, futuring techniques, and iteration; navigating through the change via adaptation, flexibility, and robustness; and experimenting with the change through deliberation, probing, and learning. However, what remains crucial is to develop suitable specifications of these strategies and embed these within the different phases of the policy cycle. Thus ideally, a long-term governance approach is anticipatory, flexible, and adaptive and capable of addressing the challenges of changing structures and agency over time while maintaining a focus on the problem-solving target setting and the chosen solution(s).

The framework does not describe specific processes or individual cases in detail, but it should be understood as an illustration of long-term governance characteristics at a more general level. Such a framework may help to structure the field of long-term policy-making, guide future research on conceptual, comparative, and empirical in-depth studies, and may provide orientation and

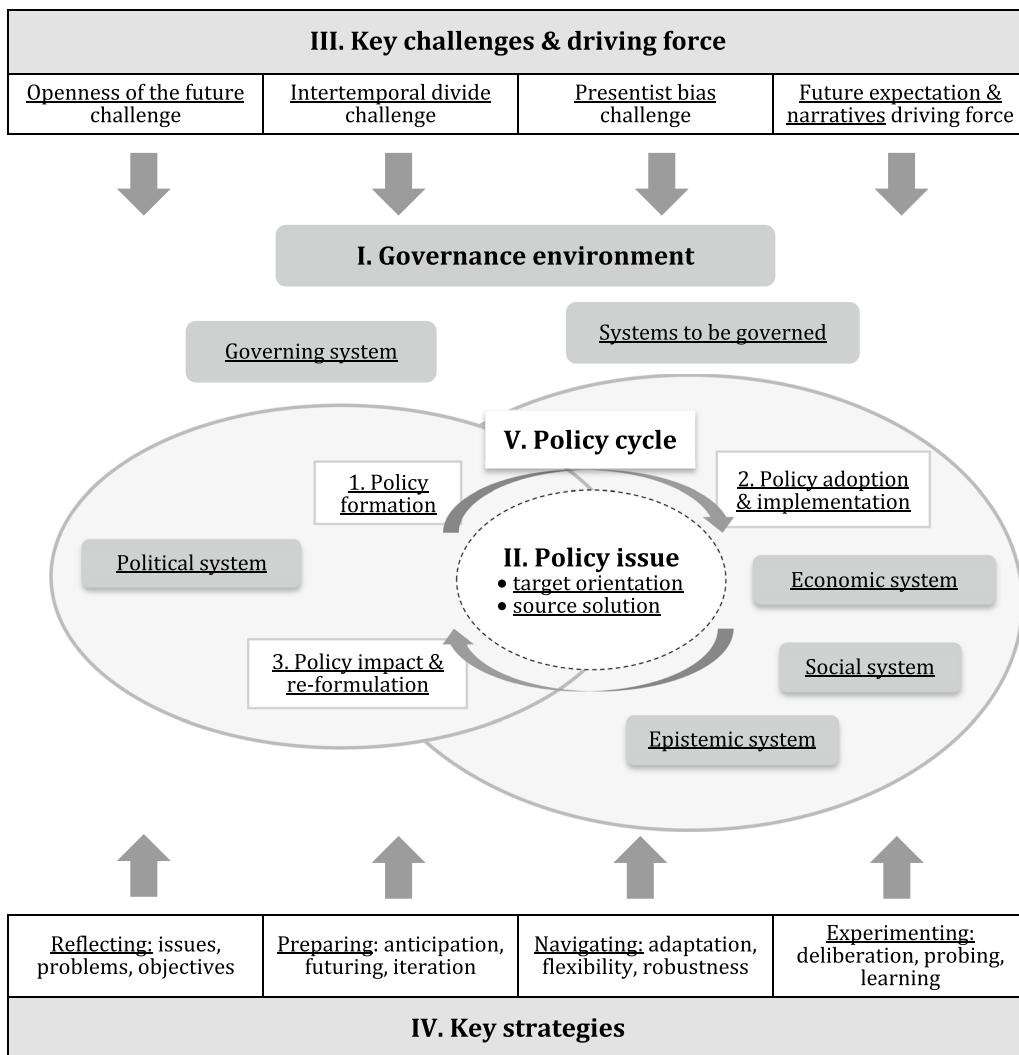


Fig. 2 Conceptual framework of long-term governance. Source: own elaboration

action knowledge for making our governance system sustainable. Stimulating and broadening research on long-term issues seems indispensable given the existence of several ‘grand challenges’ that require successful long-term governance.

Acknowledgements

We gratefully acknowledge the organizations mentioned in the “Funding” section. The research presented within this paper is a result of teamwork within the collaborative long-term governance group of ITAS, FZJ and DLR. We also would like to thank (former) group members who are not authors of the paper supporting us with their ideas, critiques, and last but not least their research. That is: Sophia Dieken, Eike Düvel, Jonas Eschmann, Laura Müller, Laura García Portela, and Lisa Schmieder. Furthermore, we want to thank the three anonymous reviewers who commented on the paper with much care and contributed to improving the quality of the paper.

Author contributions

The design and implementation of the research behind this article was designed and performed by all authors, i.e., D.S., S.V., St.S., Sa.S., S.K., M.S. and C.H.K. DS was responsible to set up the paper and wrote the very large parts

of this paper. D.S., S.V., St.S., Sa.S., S.K., M.S. and C.H.K. carefully read and commented on the several versions and helped to finalize it. All authors read and approved the final manuscript.

Funding

Open Access funding enabled and organized by Projekt DEAL. Open Access funding was enabled and organized by Project DEAL and implemented by Karlsruhe Institute of Technology (KIT). The research carried out for this article has been carried out in the Program-Oriented Funding (PoF) of Helmholtz Association according to the program “Energy System Design (ESD)” within its subtopic 1.2 (“Societally-Feasible Transformation Pathways”).

Availability of data and materials

No data sets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

¹Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany. ²Institute of Energy and Climate Research, Systems Analysis and Technology Evaluation (IEK-STE), Forschungszentrum Jülich, Jülich, Germany. ³Department of Energy Systems Analysis, Institute of Networked Energy Systems, German Aerospace Center, Oldenburg, Germany.

Received: 6 December 2023 Accepted: 15 January 2025

Published online: 26 January 2025

References

- Green DG, Newth D (2001) Towards a theory of everything? Grand challenges in complexity and informatics. *Complexity Int* 8(1)
- Hoare T, Milner R (2005) Grand challenges for computing research. *Comput J* 48(1):49–52
- Cech E (2012) Great problems of grand challenges. Problematizing engineering's understandings of its role in society. *IJESJP* 1(2):85–94
- Calvert J (2013) Systems biology. Big science and grand challenges. *BioSocieties* 8(4):466–479
- Decker M, Lindner R, Lingner S, Scherz C, Sotoudeh M (eds) (2018) „Grand Challenges“ meistern: Der Beitrag der Technikfolgenabschätzung. Nomos Verlagsgesellschaft, Baden-Baden
- Kuhlmann S, Rip A (2018) Next-generation innovation policy and Grand Challenges. *Sci Public Policy* 45:448–454
- Beck U (1986) Risk society: towards a new modernity. Sage Publications, London
- Little RG (2010) Managing the risk of cascading failure in complex urban infrastructures. In: Graham S (ed) Disrupted cities: when infrastructure fails. Routledge, London, pp 27–39
- Anja B (2018) When is the future? Temporal ordering in anticipatory policy advice. *Futures* 101:36–45
- Eshuis J, van Buren A (2014) Innovations in water governance: the importance of time. *Int Rev Adm Sci* 80(2):401–420
- Vogt H, Pukarinen A (2022) The European Union as a long-term political actor: an overview. *Polit Res Exchange*. <https://doi.org/10.1080/2474736X.2022.2043725>
- Segrave AJ, van der Zouwen MW, van Vierssen W (2014) Water planning: from what time perspective? *Technol Forecast Soc* 86:157–167
- Langmuir CH, Broecker W (2012) How to build a habitable planet. Princeton University Press, Princeton
- Benz A (2004) Governance—Modebegriff oder nützliches sozialwissenschaftliches Konzept? In: Benz A (ed) Governance—Regieren in komplexen Regelsystemen. VS, Wiesbaden
- Sweet AS (1999) Judicialization and the construction of governance. *Comp Polit Stud* 32:147–184
- Dietz T, Börner J, Förster JJ, von Braun J (2018) Governance of the bioeconomy: a global comparative study of national bioeconomy strategies. *Sustainability* 10(9):3190
- Fukuyama F (2016) Governance: what do we know, and how do we know it? *Annu Rev Polit Sci* 19:89–105
- Nye JS, Donahue JD (eds) (2000) Governance in a globalizing world. Brookings Institution Press, Washington DC
- Mayntz R (2004) Mechanisms in the analysis of social macro-phenomena. *Philos Soc Sci* 34(2):237–259
- Grande E (2012) Governance-Forschung in der Governance-Falle? Eine kritische Bestandsaufnahme. *Polit Vierteljahr* 53(4):565–592
- Mayntz R (2006) From government to governance: political steering in modern societies. In: Scheer D, Rubik F (eds) Governance of integrated product policy. Greenleaf, Sheffield, pp 18–25
- Biermann F (2007) Earth system governance as a crosscutting theme of global change research. *Global Environ Chang* 17(3–4):326–337
- Biermann F, Betsill M, Gupta J, Kani N, Lebel L, Liverman D, et al (2009) Earth System Governance: People, Places and the Planet. Science and Implementation Plan of the Earth System Governance Project Report no. 1
- Biermann F, Betsill MM, Gupta J, Kanie N, Lebel L, Liverman D, Schroeder H, Siebenhüner B, Zondervan R (2010) Earth system governance: a research framework. *Int Environ Agreem Polit Law Econ* 10:277–298
- Renn O, Laubichler M, Lucas K, Kröger W, Schanze J, Scholz RW, Schweizer PJ (2020) Systemic risks from different perspectives. *Risk Anal* 42:1902–1920
- Scheffer M (2010) Complex systems: foreseeing tipping points. *Nature* 467(7314):411–413
- Renn O (2008) Risk governance: coping with uncertainty in a complex world. Earthscan, London
- Rotmans J, Kemp R, van Asselt MB (2001) More evolution than revolution: transition management in public policy. *Foresight* 3:15–31
- Geels FW, Schot JW (2007) Typology of sociotechnical transition pathways. *Res Policy* 36(3):399–417
- Kemp R, Truffer B, Harms S (2000) Strategic niche management for sustainable mobility. In: Rennings K, Hohmeier O, Ottinger RL (eds) Social costs and sustainable mobility. Strategies and experiences in Europe and the United States. Springer, Heidelberg, pp 167–187
- Hoogma R, Weber KM, Elzen B (2005) Integrated long-term strategies to induce regime shifts towards sustainability: the approach of strategic niche management. In: Weber M, Hemmelskamp J (eds) Towards environmental innovation systems. Springer, Berlin, pp 209–236
- Kemp R, Rotmans J (2005) The management of the co-evolution of technical, environmental and social systems. In: Weber M, Hemmelskamp J (eds) Towards environmental innovation systems. Springer, Berlin, pp 33–55
- Grin J, Rotmans J, Schotz J (2010) Transitions to Sustainable development. New directions in the study of long-term transformative change. Routledge, New York
- Loorbach DA (2007) Transition Management. New mode of governance for sustainable development. International Books, Utrecht
- Geels FW (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Res Policy* 31(8–9):1257–1274
- Geels FW (2004) From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Res Policy* 33(6–7):897–920
- Geels FW (2011) The multi-level perspective on sustainability transitions: responses to seven criticisms. *Environ Innov Soc Transit* 1:24–40
- Loorbach DA (2010) Transition management for sustainable development: a prescriptive, complexity-based governance framework. *Governance* 23:161–183
- United Nations (2015) Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf. Accessed 24. May 2024
- International Energy Agency (2011) Solar Energy Perspectives. <https://iea.blob.core.windows.net/assets/2b3c53f4-1c8f-478c-a4fa-a98597cd27b/SolarEnergyPerspectives.pdf>. Accessed 24. May 2024
- O'Sullivan M (2020) Industrial life cycle: relevance of national markets in the development of new industries for energy technologies—the case of wind energy. *J Evolution Econ* 30:1063–1107
- Meckling J, Liscy P, Finnegan J, Metz F (2022) Why nations lead or lag in energy transitions. *Science* 378:31–33
- Van Assche K, Verschraegen G, Gruezmacher M (2021) Strategy for collectives and common goods: coordinating strategy, long-term perspectives and policy domains in governance. *Futures* 128:102716
- Underdal A (2010) Complexity and challenges of long-term environmental governance. *Global Environ Chang* 20(3):386–393
- Ferraro F, Etzion D, Gehman J (2015) Tackling grand challenges pragmatically: robust action revisited. *Organ Stud* 36(3):363–390
- Pahl-Wostl C, Gorris P, Jager N, Koch L, Lebel L, Stein C, et al (2021) Scale-related governance challenges in the water–energy–food nexus: toward a diagnostic approach. *Sustain Sci* 16:615–629
- Maas TY, Pauwelussen A, Turnhout E (2022) Co-producing the science–policy interface: towards common but differentiated responsibilities. *Humanit Soc Sci Commun* 9(1):1–11
- Caney S (2018) Justice and future generations. *Annu Rev Polit Sci* 21:475–493

49. Pörtner HO, Roberts DC, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, Weyer NM (2019) The ocean and cryosphere in a changing climate. *IPCC special report on the ocean and cryosphere in a changing climate*, 1155, Cambridge University Press, Cambridge
50. Goetz KH (2014) A question of time: responsive and responsible democratic politics. *West Eur Polit* 37(2):379–399
51. Bryson JM, Berry FS, Yang K (2010) The state of public strategic management research: a selective literature review and set of future directions. *Am Rev Public Adm* 40(5):495–521
52. Poister TH (2010) The future of strategic planning in the public sector: linking strategic management and performance. *Public Admin Rev* 70:s246–s254
53. Meuleman L, Veld RJ (2010) Sustainable development and the governance of long-term decisions. In: Veld RJ (ed) *Knowledge democracy*. Springer, Heidelberg, pp 255–281
54. McGinnis MD, Ostrom E (2011) SES framework: Initial changes and continuing challenges. *ECOL SOC* 1–28
55. Kooiman J (2008) Exploring the concept of governability. *J Comp Policy Anal* 10(2):171–190
56. Stauffer M, Seifert K, Ammann N, Snoeij JP (2021) Policymaking for the Longterm Future: Improving Institutional Fit. Simon Institute for Longterm Governance. Working Paper #1. https://drive.google.com/file/d/1FI11Q_hIRIT8F9PC7FieTER0wiijyJaxi/view, Accessed 24. May 2024
57. Parsons TE (1967) *Sociological theory and modern society*. Free Press, New York
58. Münch R (1982) *Basale Soziologie: Soziologie der Politik*. Westdeutscher Verlag, Opladen
59. Pressman J, Wildavsky A (1973) Implementation: how great expectations in washington are dashed in Oakland: or, why it's amazing that federal programs work at all. University of California Press, Berkeley
60. Czada R (2016) *Planen und Entscheiden als Steuerungsaufgabe und Interaktionsproblem*. In: Kamp G (ed) *Langfristiges Planen*. Springer, Berlin, Heidelberg, pp 215–249
61. Renn O, Klinke A, van Asselt M (2011) Coping with complexity, uncertainty and ambiguity in risk governance: a synthesis. *Ambio* 40:231–246
62. Renn O (1995) Style of using scientific expertise: a comparative framework. *Sci Publ Policy* 22(3):147–156
63. Zohlnhöfer R (2008) Stand und Perspektiven der vergleichenden Staatstätigkeitsforschung. In: Janning F, Toens K (eds) *Die Zukunft der Policy-Forschung Theorien, Methoden, Anwendungen*. Verlag für Sozialwissenschaften, Wiesbaden, pp 157–174
64. Jacobs AM (2016) Policy making for the long term in advanced democracies. *Annu Rev Polit Sci* 19(1):433–454
65. Caluwaerts D, Vermassen D (2023) Democratic institutions and future generations. In: Mackenzie MK, Setälä M, Kyllonen SP (eds) *Democracy and the Future. Future-regarding governance in democratic systems*. Edinburgh University Press, Edinburgh, pp 173–194
66. Smith G (2023) Democratic design for future-regarding institutions. In: Mackenzie MK, Setala M, Kyllonen S (eds) *Democracy and the future: future-regarding governance in democratic systems*. Edinburgh University Press, Edinburgh, pp 157–172
67. Bemelmans-Videc ML, Rist RC, Vedung EO (eds) (2011) *Carrots, sticks, and sermons: policy instruments and their evaluation*. Transaction Publishers, London
68. Göhler G (2009) Neue Perspektiven politischer Steuerung. *APuZ* 2:34–40. <http://www.bpb.de/apuz/33033/neue-perspektiven-politischer-steuerung?p=all>. Accessed 24. May 2024
69. Foucault M (1981) *Archäologie des Wissens*. Suhrkamp, Frankfurt am Main
70. Foucault M (1977) Die Ordnung des Diskurses (Inauguralvorlesung am College de France vom 2. Dezember 1970). Frankfurt/M: Ullstein [fr. org. 1971: *L'ordre du discours*. Paris: Gallimard]
71. von Beyme K (1997) *Der Gesetzgeber: der Bundestag als Entscheidungszentrum*. Westdeutscher Verlag, Opladen
72. Kingdon JW (1995) *Agendas, alternatives, and public policies*, 2nd edn. HarperCollins College Publishers, New York
73. Anderson JE (2003) *Public policymaking: an introduction*, 5th edn. Houghton Mifflin Company, Boston
74. Wood DB, Doan A (2003) The politics of problem definition: applying and testing threshold models. *Am J Polit Sci* 47(4):640–653
75. Jasanooff S (2004) *States of knowledge: the co-production of science and social order*. Routledge, London
76. Jasanooff S (1990) *The fifth branch: science advisers as policymakers*. Harvard University Press, Cambridge
77. Stirling A (2008) 'Opening up' and 'closing down': power, participation, and pluralism in the social appraisal of technology. *Sci Technol Hum Values* 33(2):262–294
78. Wynne B (1992) Misunderstood misunderstanding: social identities and public uptake of science. *Public Underst Sci* 1(3):281–304
79. Sabatier PA, Jenkins-Smith HC (1993) *Policy change and learning: an advocacy coalition approach*. Westview Press, Boulder
80. Frantzeskaki N, Loorbach D (2010) Towards governing infrasystem transitions: reinforcing lock-in or facilitating change? *Technol Forecast Soc* 77(8):1292–1301
81. Smith A, Stirling A, Berkhouit F (2005) The governance of sustainable socio-technical transitions. *Res Policy* 34(10):1491–1510
82. Sovacool BK (2011) An international comparison of four polycentric approaches to climate and energy governance. *Energy Policy* 39(6):3832–3844
83. Winner L (1980) Do artefacts have politics? In: MacKenzie DA, Wajcman J (eds) *The social shaping of technology*. Open University Press, Milton Keynes, pp 26–38
84. Ostrom E (2010) Polycentric systems for coping with collective action and global environmental change. *Global Environ Chang* 20(4):550–557
85. Gupta J (2014) *The history of global climate governance*. Cambridge University Press, Cambridge
86. Bartholdsen HK, Eidens A, Löffler K, Seehaus F, Wejda F, Burandt T, Oei PO, Kemfert C, Hirschhausen CV (2019) Pathways for Germany's low-carbon energy transformation towards 2050. *Energies* 12(15):2988
87. Geels FW (2014) Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective. *Theor Cult Soc* 31(5):21–40
88. Voß JP, Smith A, Grin J (2009) Designing long-term policy: rethinking transition management. *Policy Sci* 42(4):275–302
89. Bornemann B, Strassheim H (2019) Governing time for sustainability: analyzing the temporal implications of sustainability governance. *Sustain Sci* 14(4):1001–1013
90. Meadowcroft J (2009) What about the politics? Sustainable development, transition management, and long term energy transitions. *Policy Sci* 42(4):323–340
91. Konrad W, Scheer D, Weidtmann A (eds) (2020) *Bioökonomie nachhaltig gestalten: Perspektiven für ein zukunftsfähiges Wirtschaften*. Springer VS, Wiesbaden
92. Venghaus S, Stark S, Hilgert P (2024) Transformation towards a sustainable regional bioeconomy—a monitoring approach. In: Letmathe P, Roll C, Balleer A, Böschen S, Breuer W, Förster A et al (eds) *Transformation towards sustainability*. Springer International Publishing, Cham, pp 201–229
93. Scoones I, Leach M, Newell P (eds) (2015) *The politics of green transformations*. Routledge, New York
94. Hollands RG (2020) Will the real smart city please stand up? Intelligent, progressive or entrepreneurial? *The Routledge companion to smart cities*. Routledge, New York, pp 179–199
95. Kallis G, Kostakis V, Lange S, Muraca B, Paulson S, Schmelzer M (2018) Research on degrowth. *Annu Rev Environ Resour* 43:291–316
96. Stanton MCB, Roelich K (2021) Decision making under deep uncertainties: a review of the applicability of methods in practice. *Technol Forecast Soc* 171:120939
97. Walker WE, Marchau VA, Swanson D (2010) Addressing deep uncertainty using adaptive policies: introduction to section 2. *Technol Forecast Soc* 77(6):917–923
98. Stirling A (1998) Risk at a turning point? *J Risk Res* 1(2):97–109
99. van Asselt M (2000) *Perspectives on uncertainty and risk*. Springer, Heidelberg
100. Stirling A (2007) Risk assessment in science: towards a more constructive policy debate. *EMBO Rep* 8:309–315
101. Grunwald A (2018) *Technology assessment in practice and theory*. Routledge, London
102. Beckert J (2016) *Imagined futures: fictional expectations and capitalist dynamics*. Harvard University Press, Cambridge

103. Perrow C (1984) Complexity, coupling and catastrophe. In: Perrow C (ed) *Normal accidents: living with high-risk technologies*. Basic Books, New York, pp 62–100
104. Voß JP, Kemp R (2006) Introduction. In: Voß JP, Bauknecht D, Kemp R (eds) *Reflexive governance for sustainable development*. Edward Elgar, Cheltenham
105. Lindblom CE (1979) Still muddling, not yet through. *Public Admin Rev* 39:517–526
106. Wildavsky A (1979) Speaking truth to power: the art and craft of policy analysis. Little Brown, Boston
107. Hager MA (2003) Policy without polity? *Policy analysis and the institutional void*. *Policy Sci* 36(2):175–195
108. Boston J, Bagnall D, Barry A, Head T, Hellyer G, Sharma P (2019) Foresight, insight and oversight: Enhancing long-term governance through better parliamentary scrutiny. Victoria University of Wellington, Institute for Governance and Policy Studies, <https://ir.wgtn.ac.nz/server/api/core/bitstreams/47f1c122-8e2e-4cce-9bd9-539e33460ba9/content>, Accessed 24. May 2024
109. Kahneman D, Slovic P, Tversky A (eds) (1982) *Judgment under uncertainty: heuristics and biases*. Cambridge University Press, Cambridge
110. Tasaki T, Kameyama Y (2024) Considering future generations in democratic governance. *Polit Gov* 12:8397
111. Pinch TJ, Bijker WE (1984) The social construction of facts and artefacts: or how the sociology of science and the sociology of technology might benefit each other. *Soc Stud Sci* 14(3):399–441
112. Gigerenzer G (1991) How to make cognitive illusions disappear: beyond "heuristics and biases". *Eur Rev Soc Psychol* 2:83–115
113. Gigerenzer G (2000) Adaptive thinking: rationality in the real world. Oxford University Press, Oxford
114. Gigerenzer G (2007) Short Cuts: the intelligence of the unconscious. Penguin Books, London
115. Lösch A, Grunwald A, Meister M, Schulz-Schaeffer I (eds) (2019) *Socio-technical futures shaping the present: empirical examples and analytical challenges*. Springer VS, Wiesbaden
116. van Lente H, Rip A (1998) Expectations in Technological Developments: An Example of Prospective Structures to Be Filled in by Agency. In: Disco C, van der Meulen B (ed) *Getting New Technologies Together: Studies in Making Sociotechnical Order*. de Gruyter, Berlin, pp 203–229
117. Brown N, Michael M (2003) A sociology of expectations: retrospective prospects and prospecting retrospects. *Technol Anal Strateg* 15(1):3–18
118. Jasianoff S, Kim SH (2009) Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. *Minerva* 47:119–146
119. Rip A (2009) Technology as prospective ontology. *Synthese* 168:405–422
120. Jasianoff S (2016) The power of technology. In: Jasianoff S (ed) *The ethics of invention: technology and the human future*. W.W. Norton & Company, New York, pp 1–30
121. Borup M, Brown N, Konrad K, van Lente H (2006) The sociology of expectations in science and technology. *Technol Anal Strateg* 18(3–4):285–298
122. Voß JP, Kemp R (2005) Reflexive Governance for Sustainable Development. Incorporating feedback in social problem solving. Paper for ESEE Conference, June 14–17, 2005, Lisbon (2005)
123. Voß JP, Bauknecht D, Kemp R (eds) (2006) *Reflexive governance for sustainable development*. Edward Elgar, Cheltenham
124. Kleinman DL (2000) Science, technology and democracy. New York State University Press, Albany
125. Jasianoff S (2003) Technologies of humility: citizen participation in governing science. *Minerva* 41:223–244
126. Ottinger G (2009) Buckets of resistance: Standards and the effectiveness of citizen science. *Sci Technol Human Values* 35(2):244–270
127. Rawls J (2001) Justice as fairness: a restatement. Harvard University Press, Cambridge
128. Rawls J (2005) Political liberalism. Columbia University Press, New York
129. González-Ricoy I, Gosseries A (eds) (2016) *Institutions for future generations*. Oxford University Press, Oxford
130. Fuerth LS (2009) Foresight and anticipatory governance. *Foresight* 11(4):14–32
131. Fuerth LS, Faber EM (2012) Anticipatory governance practical upgrades: equipping the executive branch to cope with increasing speed and complexity of major challenges. National Defense University, Center for Technology & National Security Policy
132. Boyd E, Nykvist B, Borgström S, Stacewicz IA (2015) Anticipatory governance for social-ecological resilience. *Ambio* 44:149–161
133. Scheer D, Nabitz L (2019) Klimaverträgliche Energiezukünfte (nicht) wissen. *TATuP-Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis* 28(3):14–19
134. Scheer D, Schmidt M, Dreyer M, Schmieder L, Arnold A (2022) Integrated policy package assessment (IPPA): a problem oriented research approach for sustainability transformations. *Sustainability* 14(3):1218
135. Berkes F, Colding J, Folke C (eds) (2003) *Navigating social-ecological systems: building resilience for complexity and change*. Cambridge University Press, Cambridge
136. Scheer D, Grunwald A (2017) Orientierungswissen für die Energiewende: Der Roadsmap-und-Navigation-Ansatz. *Gaia* 26(2):155
137. Dreyer M, Edenhofer O, Fischedick M, Gaschnig H, Grunwald A, Henning HM, Hoffmann C, Hufendiek K, Jaeger C, Knodt M, Kost C, Luderer G, Mack B, Matthies E, Ober S, Pahle M, Renn O, Rodi M, Scheer D, Staiß F, Stückrad S, Thomas H (2019) Wegbeschreibungen zum klimaneutralen Energiesystem: Abschlussbericht 2019; Kopernikus-Projekt Energiewende-Navigationssystem; ENavi. Potsdam: Geschäftsstelle des Kopernikus-Projekts Energiewende-Navigationssystem. http://www.strise.de/fileadmin/user_upload/PDFs/Abschlussbericht_191216_ENavi-Bericht_web.pdf. Accessed 24. May 2024
138. Dietz T, Ostrom E, Stern PC (2003) The struggle to govern the commons. *Science* 302(5652):1907–1912
139. Folke C, Hahn T, Olsson P, Norberg J (2005) Adaptive governance of social-ecological systems. *Annu Rev Environ Resour* 30:441–473
140. Boyd E, Folke C (eds) (2011) *Adapting institutions: governance, complexity and social-ecological resilience*. Cambridge University Press, Cambridge
141. Pot W, Scherpenisse J, Hart P (2023) Robust governance for the long term and the heat of the moment: temporal strategies for coping with dual crises. *Public Admin* 101(1):221–235
142. Hager MA (2009) Authoritative governance: policy making in the age of mediatization. Oxford University Press, Oxford
143. Goodin RE, Dryzek JS (2006) Deliberative impacts: the macro-political uptake of mini-publics. *Polit Soc* 34(2):219–244
144. Mbah M, Kuppler S (2021) Raum sensible long-term governance zur Bewältigung komplexer Langzeitaufgaben. Robuste Langzeit-Governance bei der Endlagersuche. Soziotechnische Herausforderungen im Umgang mit hochradioaktiven Abfällen. Transcript, Bielefeld, pp 413–446
145. Kuppler S, Hocke P (2019) The role of long-term planning in nuclear waste governance. *J Risk Res* 22(11):1343–1356
146. Schmieder L, Scheer D, Gaiser J, Jendritzki I, Kraus B (2023) Municipalities as change agents? Reconsidering roles and policies in local energy sector-coupling. *Energy Res Social Sci* 103:103210
147. Zetsche DA, Buckley RP, Barberis JN, Arner DW (2017) Regulating a revolution: from regulatory sandboxes to smart regulation. Fordham J Corp Financ Law 23:31–103
148. Hossain M, Leminen S, Westerlund M (2019) A systematic review of living lab literature. *J Clean Prod* 213:976–988
149. Biegelbauer P (2013) Wie lernt die Politik? Lernen aus Erfahrung in Politik und Verwaltung. Springer, Heidelberg
150. Sträter O (2021) Achtsamkeit und Fehlerkultur als notwendige Sicherheitsleistung. In: Brohmann B, Brunnegräber A, Hocke P, Isidoro Losada AM (eds) *Robuste Langzeit-Governance bei der Endlagersuche*. Transcript, Bielefeld, pp 447–462
151. Lasswell HD (1956) The decision process: seven categories of functional analysis. Bureau of Governmental Research, College of Business and Public Administration, University of Maryland
152. Jann W, Wegrich K (2003) Phasenmodelle und Politikprozesse: Der Policy Cycle. In: Schubert K, Bandelow NC (eds) *Lehrbuch der Politikfeldanalyse*. De Gruyter Oldenbourg, Berlin, pp 71–105
153. Foxon TJ, Reed MS, Stringer LC (2009) Governing long-term social-ecological change: what can the adaptive management and transition management approaches learn from each other? *Environ Policy Gov* 19(1):3–20

154. Kydland FE, Prescott EC (1977) Rules rather than discretion: the inconsistency of optimal plans. *J Polit Econ* 85(3):473–491
155. Rosenbloom D (2017) Pathways: an emerging concept for the theory and governance of low-carbon transitions. *Global Environ Chang* 43:37–50
156. Scheer D, Becker F, Hassel T, Hocke P, Leusmann T, Metz V (2024) Trittsicherheit auf Zukunftspfaden? Ungewissheitsbewältigung bei der Entsorgung hochradioaktiver Abfälle. In: Eckhardt E, Becker F, Mintzlaff V, Scheer D, Seidel R (eds) *Entscheidungen in die weite Zukunft*. Springer Nature VS, Wiesbaden, pp 113–140
157. Lindblom CE (1959) The science of ‘muddling through.’ *Public Admin Rev* 19:79–88
158. Etzioni A (1967) Mixed-scanning: a “third” approach to decision-making. *Public Admin Rev* 27(5):385–392
159. Etzioni A (2016) Mixed scanning model of decision making in organizations. In: Farazmand A (ed) *Global encyclopedia of public administration, public policy, and governance*. Springer, Cham. https://doi.org/10.1007/978-3-319-31816-5_26-1
160. Höglund L, Holmgren Caicedo M, Mårtensson M, Svärdsten F (2018) Strategic management in the public sector: how tools enable and constrain strategy making. *Int Public Manag J* 21(5):822–849
161. Pot WD, Dewulf A, Termeer CJ (2022) Governing long-term policy problems: dilemmas and strategies at a Dutch water authority. *Public Manag Rev* 24(2):255–278
162. Hocke P, Kuppler K, Smeddinck U, Hassel T (eds) (2022) *Technical monitoring and long-term governance*. Nomos, Baden-Baden
163. Scott JC (1999) Seeing like a state: how certain schemes to improve the human condition have failed. Yale University Press, Yale
164. Bowker GC, Star SL (1999) *Sorting Things out: classification and its consequences*. MIT Press, Cambridge
165. Gross M (2007) The unknown in process: dynamic connections of ignorance, non-knowledge and related concepts. *Curr Sociol* 55(5):742–759
166. McGoey L (2012) The logic of strategic ignorance. *Brit J Sociol* 63(3):533–576

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.