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Harnessing legal system complexity for radical shifts to sustainability

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Harnessing legal system complexity for radical shifts to sustainability

Abstract:

Responding to accelerating global environmental change and its key drivers requires swift and decisive governance action at multiple scales. Despite well-developed theories on radical sustainability shifts, including policy mixes, education, and civic and corporate action, many approaches fail to deliver timely results at scale. We argue that a key reason for this failure is a simplified framing of how change in the law is produced and how such legal change in turn impacts social-ecological systems to be governed. Instead, law should be understood as a complex system of governance in which surprising system dynamics emerge in connection with virtually all governance initiatives that seek to promote sustainability. This paper explores law as a complex system and examines how legal systemic change for sustainability can be theorised and operationalised accordingly and offers a research agenda for this critically important line of work.

Keywords: Radical shift to sustainability, legal systems, complexity, targeted interventions, cascading effects, regulatory impact evaluation

1 Introduction

Humanity has crossed several planetary boundaries (Richardson et al. 2023) and is fast approaching Earth-system tipping points related to those boundaries (Tobian et al. 2024). Addressing these crises requires a radical shift in production and consumption – one that is intentional, multiscale, far-reaching, and just (Milkoreit et al. 2024). A shift of sufficient magnitude can be advanced by transitions in technologies, business models, and governance approaches (Köhler et al. 2019), and by broader transformative change in systems of culture (Meadows 1999), education (Abson et al. 2017), economy (Parrique et al. 2019), and institutions (Mazzucato 2023). In this article, we define ‘radical shift to sustainability’ as an intentional, multiscale process of social system transitions and transformations that protect ecological systems while sustaining their social foundations.

Scholars of sustainability governance recognise social-ecological systems (SES) as complex and adaptive, where biophysical and social components interact through decentralised networks, feedback loops, and subsequently emergent, nonlinear and cascading dynamics (Lenton et al. 2023). An example of complexity in coupled biophysical and social systems is how small biophysical changes, such as slight increases in seawater temperature, can lead to disproportionately large negative impacts, including intensified hurricanes affecting both nature and society (e.g., Radu, Toumi & Phau 2013). Furthermore, in coupled human-nature systems, these biophysical dynamics can trigger rapid scaling of social movements, such as climate activist groups (Ball 2006). Interactions between biophysical and social systems, such as the global reliance on fossil fuels affecting the climate system, define the complexity of SESs. A key consequence of complexity is the unpredictability of future states, where small initial changes can lead to disproportionately large systemic changes. Such realisation marks a stark shift in studying social-ecological systems and exposes gaps in understanding their change. (Folke et al. 2005)

Constantly improving understanding of complex systems has advanced deeper theories of social-ecological change. However, this improved knowledge of complex systems has not shifted understanding that legal systems are complex systems as well and are essential for governing complex social-ecological systems (Soininen et al. 2021). We argue that such a conceptual shift is necessary: law as a system of governance should be understood and approached as a complex system.

In the current scholarly setting, however, law is still seen as a ‘simple’ policy instrument, easily altered for economic, social, or political convenience. Changes in legal instrumentation are typically expected to deliver societal changes in a linear “make it so” way (O’Brien 2021). This is best illustrated by scientists who often propose straightforward legal changes or policy adjustments on specific issues (e.g., “new law is needed for...”). The complexity of law itself, and the legal systems within which laws change, are seldom considered (Ruhl et al. 2019). Rather, legal scholars and practitioners are invited to contribute almost as an afterthought – if at

all (Triyanti et al. 2023). This feature in the existing sustainability scholarship poses significant challenges for implementing a radical shift to sustainability. No competent ecologists today would suggest introducing new species to an ecosystem without considering the impact on ecosystem dynamics (Solé and Levin 2022), and the same logic is true of financial and economic systems (Halaj et al. 2024). Why would legal systems be any different? (Webb 2005)

The simplified view of law as a policy instrument acting as a simple “lever” to manage social conditions obscures the challenge of crafting legal tools with the necessary scope, precision, and force to address accelerating environmental change. This is because the legal system itself is composed of numerous interactions between actors (e.g., legislatures, courts and authorities operating at multiple scales and sectors of governance) and a multitude of existing legal materials regulating most aspects of social life (Ruhl et al. 2017). Law emerges as a complex system through the interactions of numerous actors, legal institutions, and materials. Any new or revised legal instruments thus must enter, adapt and be adapted by the existing web of interactions in a complex-adaptive legal system. While some of the interactions in a legal system may change with novel legal instrumentation, such as legally binding climate change mitigation targets, many others may change only slightly, if at all, such as firmly entrenched property rights and contractual obligations (Lierman 2014). Selecting which components to change and how or predicting their impact on unchanged components in the legal system and vice versa, is extremely difficult. The omission of legal systemic dynamics severely undermines any comprehensive theory of change in SES contexts, such as a radical shift to sustainability.

To address the existing gaps in sustainability scholarship, we propose a novel theory of change in legal systems focusing on strategically placed interventions, supported by a complexity-sensitive regulatory impact assessment. These legal interventions include introducing or changing targeted points of cross-reference (nodes) in the complex-adaptive legal system. Examples include legislative changes targeting land-use rights or using consumer protection litigation claims to assign liability for climate change to large fossil fuel producers (Kotzé et al. 2024).

To support our argument, section 2 explores how law functions as a complex-adaptive system. Section 3 examines how change in legal systems can be approached through targeted interventions rather than broad legal reforms aimed at redesigning SES frameworks at once. Given the uncertainty of such interventions, section 4 considers which regulatory impact assessment methods and tools best evaluate node-targeted change in complex-adaptive legal systems within SES contexts. Section 5 concludes by establishing the beginnings of a novel theory of change and a coupled research agenda for the study of legal systems in SES contexts. The prospects of the theory hold promise of producing actionable knowledge for promoting radical shifts to sustainability that account for the complexity of legal systems.

2 Law as a complex system

Ruhl et. al (2017), describe legal systems as complex-adaptive systems comprising a wide diversity of institutional actors (e.g., legislatures, agencies, courts), norms (e.g., due process, equality, fairness), and legal materials (e.g., statutes, regulations, court orders) that are interconnected through a multitude of processes (e.g., legislating, rulemakings, trials). These actors, norms and materials form a network with central nodes that are points in the network with considerable influence on the overall system configuration (Ruhl et al. 2017). Legislatures and high courts – and particularly important norms and materials they produce (e.g., constitutional norms) – typically form such nodes. The legal systems’ actors, norms and materials interact through feedback mechanisms, such as legislative oversight, judicial review, and appellate processes. These operate within both hierarchical and non-hierarchical networks, including national and subnational governance structures and cross-references within and across statutes. These dynamics often lead to self-organisation, seen in the evolution of common law doctrines or increasingly detailed statutory codes. Further, there is an intricate interlinkage and co-evolution between the components of the system (institutional actors, legal materials and norms). (Murray et al. 2019) Table 1 summarizes how law’s complexity challenges established beliefs concerning law and legal systemic change among scientists and traditional legal scholarship.

Table 1. Comparison between scientists’, traditional legal scholars’, and complexity science -informed legal scholars’ view of law, legal systemic change, legal impact evaluation. Table 1’s rows represent four key variables: the nature of law, its actors, its impacts, and methods for understanding them. We argue for a complexity-sensitive perspective across all four and elaborate on this further below.

Failing to understand law as a complex system leads to two mistaken assumptions about the role of law in governance. First, one gets an overly optimistic (and democratic) impression of the feasibility of legal systemic change. Second, a failure to appreciate the complex-adaptive system qualities of legal systems yields an incorrect and an overly optimistic impression of how legal change impacts the governance of SES. (Ruhl et al. 2017, 1377)

Considering the first point, even though law in principle can be changed and manipulated at will, in practice this is difficult because the legal landscape has become crowded with instruments accumulating over time, sometimes over hundreds of years or longer (Kim 2013). Moreover, the legal system consists of interactions between numerous actors, norms and legal materials, with no one actor having exclusive competence to drive – and insight to design – legal system change. As legal norms and materials accumulate over time, they create a system that resists sweeping legislative overhauls for sustainability, or for any other singular purpose. While legal instrumentation is an important driver for the radical shift to sustainability, the well-established characteristics of the complex legal system simultaneously enable and conserve current overproduction and excessive consumption and justify many associated injustices (Pascual et al. 2023).

Considering the second point, when law is not treated as a complex system, the co-evolutions of law and SES – including the Earth system – that it is meant to govern, are missed. Legal systems and their specific instruments operate as part and parcel of broader policy mixes and governance arrangements, which jointly, but only in part, incentivise individuals as well as corporate and institutional actors to behave in a certain way (Day 2024). These systems of governance are in turn coupled with the social-ecological systems to be governed. The impact of a legal change on individual, corporate, and institutional behaviour depends on interactions within and across these systems. Moreover, legal interventions can – while seemingly solving a problem in an SES – have significant unintended consequences and may cause problem-shifting to other domains in the social-ecological system (Kim and Bosselmann 2013). As an example of this unintended problem-shifting effect, the early EU biofuels policies promoted biomass-based fuels as substitutes for fossil fuels, driving a systemic shift toward the development of a new industrial sector (EU Renewable Energy Directive, 2009/28/EC). Environmentally, they induced land-use changes, including indirect land-use change, where agricultural land was repurposed for biomass production, forcing agricultural expansion elsewhere to meet food and feed demand. Socially, this competition for agricultural land contributed to biodiversity loss and other negative dynamics such as rising food prices (Van Noorden 2013). The systemic change in creating the biofuel industry initiated an ongoing evolution in the legal framework governing biofuels, marked by continuous adjustments and refinements aimed at enhancing their sustainability (Kalimo et al. 2025).

Rather than being designed as unsustainable, legal systems emerge as such with recurring feedback loops typically undoing much of the steering effect of ambitious changes in policy and associated legal instrumentation (Ruhl et al. 2017). For instance, the 2019 European Green Deal (EGD) sought to drive transformative change to sustainability by framework legislation and endeavouring to integrate broad policy goals and instruments from various sectors of the legal system. Its impact on influencing the legal system and social-ecological systems remains, however, questionable. This is due to the EGD – as any other EU policy and legal framework – being bound by the EU’s primary (‘constitutional’) law as enshrined in the EU Treaties. The Treaties at present are founded on competitive internal markets and their private law foundations, such as protection of property rights. As such, the EGD introduces sustainability goals and legal instruments without revising the EU Treaty framework subsequently creating a misalignment with the EU’s substantive constitution, which is founded on competitive free market thinking (Chiti 2022). In so doing, the EGD delegates a “mission impossible” to the EU member states (Chiti 2022) leading to considerable constitutional contestation at the national level (see, e.g., Huhta & Romppanen 2023) and significantly hindering progress toward the EGD goals. In this way, constitutional and other feedback loops in the complex legal system can undo much of the legal systemic change and the subsequent steering effect of the EGD and the related sustainability-seeking legislation.

Considering these features of legal systems, the next section proposes a path-breaking perspective on scalable legal change. We argue that supposedly small interventions and seemingly powerless actors can have a disproportionate impact on legal systemic and SES change if they target strategic connections (nodes) within the network of legal actors, norms and materials.

3 Navigating complex legal systems: emphasising targeted legal interventions

The legal complexity described in Section 2 often obstructs the radical shift to sustainability, creating frustration over unclear influence pathways, but complexity does not necessarily prevent legal change (Webb 2005). With power dispersed globally and system interactions scaling unpredictably, well-targeted strategic interventions by individuals, civic groups, companies, and public authorities can exert significant impact (Webb 2005, 238–241). Such influence, regardless of the procedure, can foster diverse legal responses to sustainability challenges and drive legal system evolution. Legal system complexity can thus catalyse legal system adaptation or transformation, if necessary, to address accelerating environmental change (Garmestani et al. 2019). As shown in Table 1, the key question is how viewing law as a complex-adaptive system helps identify change agents, their targets, timing, and actions.

The shift to sustainability is currently mostly pursued through large legal framework measures, such as climate and biodiversity laws at multiple levels of governance (Huhta et al. 2024), including the EGD discussed in section 2. This may be explained by thinking that big challenges require big solutions. While valuable, this approach is resource-intensive and risks overestimating legal frameworks' effectiveness due to legal system complexity while undervaluing or dismissing the transformative potential of smaller, strategically targeted interventions as no more than “small wins”.

We argue that there is a need to shift focus from large legal framework measures, such as the EGD, to strategically-placed efforts to influence complex legal systems. We call these efforts *strategically targeted legal interventions*; in that they take aim at seemingly small but potentially *powerful nodes* of the legal system with capacity to trigger expansive legal systemic change. This concept of legal interventions parallels the concept of leverage points, highlighting areas in complex-adaptive systems where “a small shift in one thing can produce big changes in everything” (Meadows 1999, 1). While leverage point thinking has gained considerable attention in relation to sustainability transformation (see e.g., Linnér and Wibeck 2021), there has been limited attention given to *legal* systemic levers. In a leverage point context, law is often seen as a lever that can be used to move a leverage point in an SES through its role as a policy instrument producing static rules with direct effect (Table 1; Bolton 2022). While this may be the ultimate output of the legal system, like the SES literature envisions, this conception fails to appreciate that building that legal system output is challenged by the nature of law as a complex-adaptive system. For this reason, there is a need to conceptualise first how to leverage change within the complex legal system that can then drive positive change in the SES' to be governed. In short,

although law can deliver levers to drive change in social-ecological systems, building those levers is no easy task—it requires navigating the legal system’s complexity. This dynamic is presented in Figure 1.

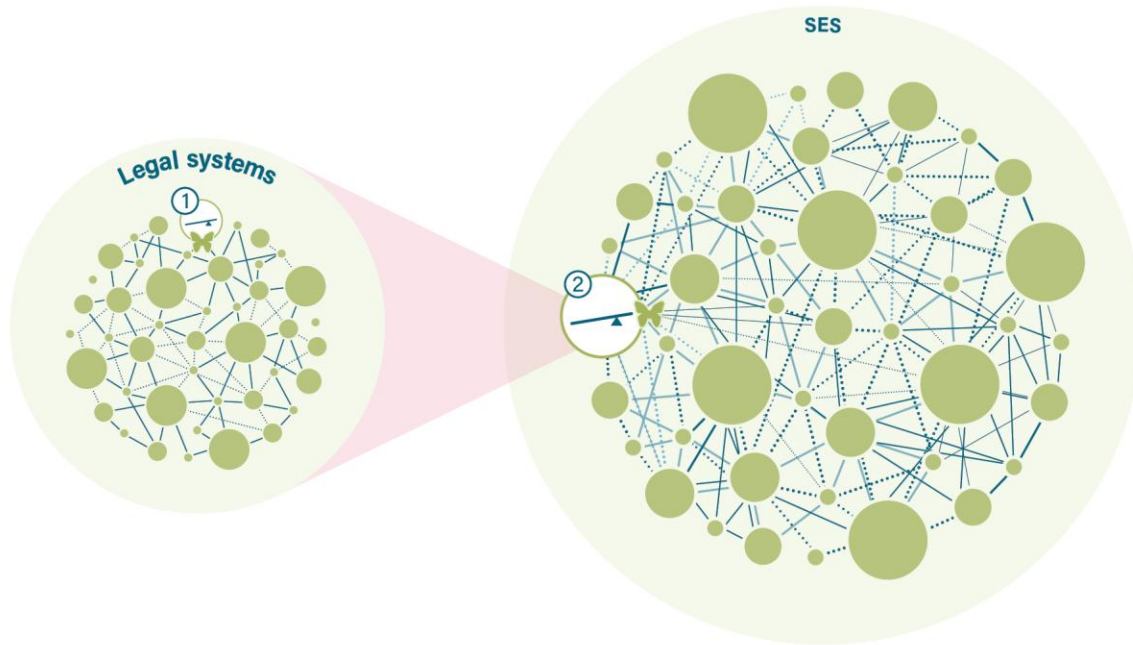


Figure 1. The interaction between complex legal systems and social-ecological systems and the need to conceive levers within the legal node network that have potential to leverage positive change for sustainability in SES’s. In ideal circumstances, the complex legal-system and SES levers can bring-about a butterfly-effect on larger systemic change.

In section 2 we used the EU Green Deal as an example of how ambitious framework legislation of broad scope can have quite limited impact in a legal system. Conversely, small legislative changes can yield far-reaching impacts if well-targeted on the central nodes of the legal network. For example, in 2023 the small U.S. state of Vermont sparked a new trend by adopting liability mechanisms from the 1980 federal Superfund law – originally for hazardous waste remediation – into state legislation imposing statutory liability on fossil fuel companies for climate-related economic damages (Cartwright 2024). The law does not establish a complex sweeping emissions regulatory regime; instead, it imposes liability on the largest fossil fuel companies for their proportional share of climate change costs from 1995 to 2024. Facing that prospect going forward would directly affect the liable entities’ behaviour without direct regulation. Vermont’s idea has since spread to other states, including New York’s adoption of a similar statutory liability program in 2024. While (unsurprisingly) companies have challenged the laws in court, this targeted intervention has substantially shifted the broader legal dynamics of climate change

liability (Savaresi et al. 2024). These examples demonstrate how different actors are experimenting to influence strategic nodes in the legal network and fine tune influencing strategy based on feedback from legal institutions, such as the courts. As invoking change in complex legal systems contains high uncertainty, even the best efforts to target the strategic nodes are oftentimes unsuccessful in driving legal systemic change.

In a judicial context, the surge of climate liability litigation over the past decade – seeking to hold fossil fuel producers and major emitters accountable for climate-related harm – also illustrate how grassroots actors are identifying strategic nodes in legal systems with targeted interventions can potentially drive legal system and SES change (Weller and Tran 2022). Although the effectiveness of this and similar lines of climate litigation against state actors and companies is subject to debate (Setzer et al. 2024), it has quickly evolved from isolated cases to a global scale. There seems to be increasing agreement that “domestic courts and judges offer valuable and often innovative pathways for governing global challenges” (Angstadt 2022, 222), including climate change. The number of climate-related court cases is rising rapidly, placing courts at the centre of climate disputes (UNEP, 2023). This shift offers a valuable opportunity to shape climate laws and policies, and the upward trend is likely to continue in global climate governance. Courts gradually become more influential climate governance actors by being strategically prompted by civil society actors and, in some instances, also more assertive in their judgments and able to influence the course and outcomes of political and law-making processes related to climate change.

In the U.S., for example, individual litigants initially brought common law nuisance claims in federal courts but were thwarted by procedural and jurisdictional challenges. Shifting to state courts, cities and states are invoking liability under state fraud and consumer protection laws (Ganguly et al. 2018). In a European context, cases such as *Royal Dutch Shell* and *KlimaSeniorinnen* are also visible examples of climate litigation. While the former sought to force a major oil producer (Shell) to assume an ambitious role in mitigating climate change and implementing action via value chain agreements across the globe (but later scaled back by a higher court), the latter presented climate change as a threat to human rights and subsequently made climate change a foundational human rights question (*Milieudéfensie et al. v. Royal Dutch Shell plc*, ECLI:NL:RBDHA:2021:5337 and *Verein KlimaSeniorinnen Schweiz and Others v. Switzerland*, 53600/20, 9.4.2024). Both illustrate how small adjustments in enforcing corporate responsibility and human rights obligations can start to challenge the legal status quo and potentially trigger cascading effects across governance levels later.

When introducing legal interventions – whether legislative or judicial – it is crucial to recognise that these changes trigger both positive and negative feedback loops within the legal system and the broader governance of social-ecological systems where law operates. As discussed above, a court’s creative re-interpretation of the procedural rules such as the standing rights of claimants seeking access to courts in environmental matters may open a new, influential avenue for actors within the legal system to effectively challenge laws or practices hindering a radical shift to

sustainability. Similarly, a successful, strategically targeted sustainability innovation, like climate litigation or evolving climate legislation that creates critical legal mass, can prompt counter proposals based on socio-economic rights (e.g., the right to property or to conduct a business) (Savaresi et al. 2024).

We have argued for strategically targeted legal interventions informed by legal system complexity to support radical sustainability, illustrating how they can both enable and hinder progress toward sustainability. Given the legal system's inherent complexity, identifying such interventions is challenging, and misapplication may lead to unforeseen, counterproductive consequences, underscoring the need for experimentation and learning. Consequently, approaches relying on targeted interventions benefit from complexity-sensitive impact evaluation methods and tools to guide their placement and learn from resulting feedback, as discussed in the following section.

4 Complexity-sensitive impact evaluation of legal interventions

Over the past two decades, Regulatory Impact Assessment (RIA) has been a key tool for policymaking in both OECD and developing countries, enhancing the quality, transparency, and effectiveness of legislation (Kamkhaji et al. 2019). For purposes of targeted legal interventions, the main issue with current RIAs is twofold. First, while they assess governance, social, economic, and environmental impacts broadly, they rarely consider the effects of legal interventions on the legal system itself, aside from some constitutional impacts (OECD 2020). RIA guidelines recommend identifying cross-cutting regulatory issues and adopting a systemic policy approach to enhance coherence (OECD 2020). However, they overlook the need within the RIA process for a systemic understanding of complex legal dynamics presented in section 2. This is notable, as legal system interactions are just as crucial as governance and social-ecological factors for both ex-ante and ex-post assessments of regulatory and social impacts. Recognising that legal, governance, and SES domains are not isolated but interwoven components within a system-of-systems is therefore essential.

From a complexity perspective, the second major challenge with current RIAs is their reliance on a linear theory of change. This should be replaced with a CAS-informed impact logic that accounts for the nested, emergent, and non-linear nature of social-ecological, governance, and legal systems. Linear models, rooted in reductionist epistemology and simplistic causality, are problematic in a CAS framework. Table 2 summarises the contrast between complexity-sensitive and traditional theories of change.

Table 2. Contrasting traditional regulatory impact assessment and complexity-sensitive impact evaluation.

Traditional RIA assesses causality through study designs and estimation strategies that allow researchers to draw conclusions from data (Hill & Stuart 2015). It typically asks: What are the causal effects of an intervention? A common approach is the randomised controlled trial (RCT). In this design, any average difference in a pre-specified outcome between trial groups is

attributed to the intervention, assuming standard statistical thresholds for sampling uncertainty. Other influencing factors are treated as external or fixed. An alternative approach to causal inference views interventions as part of broader mechanisms, acting as one ingredient in a ‘causal cake’ (Cartwright & Hardie 2012). In this view, causal factors work in conjunction or together within causal packages to produce effects. In contrast, Pawson and Tilley (1997) proposed a complexity-sensitive approach, which embodies elements of this second approach. Complexity-sensitive evaluations ask: What difference did the intervention make across groups and contexts? How and why did it have an effect, if any? What other factors contributed to the observed outcomes?

Traditional and complexity-sensitive RIAs differ in epistemology and how evaluation knowledge is applied. Complexity-sensitive RIA shifts from a reductionist, hierarchical focus on outcomes and key performance indicators toward building information platforms for learning. Examples of this approach are emerging, particularly in environmental impact assessments (EIA) for public investments. Complexity-sensitive RIA prioritises co-produced, participatory methods to capture diverse perspectives, develop system-level insights, and tell human stories. Such evaluations aim to capture horizontal complexity (local organisations and actors) and its interaction with vertical complexity (national actors within local systems). Evaluators act as ‘learning partners’ (French et al. 2023), with evaluation knowledge recognised as one of many influences shaping learning in complex systems.

Combining the broadened scope of RIA to also include complex legal systemic impact of regulatory interventions (our first point) and rethinking causal inference, evaluation questions, and the role of evaluation knowledge (our second point) makes a strong case for revising the current RIA framework. We propose three key changes to drive this shift.

Firstly, emphasising sense-making and meaning-making deepens understanding of the evaluation context and strengthens commitment. This is fundamentally a self-organising process, where individuals act based on their own cognition and choices rather than merely reacting to external pressures (Comfort 1994). Within legal systems, sense-making involves structuring the unknown amidst a dense web of interacting statutes, actors, and norms, as actors navigate diverse institutional roles and evolving rules. This process of integrating discrete informational stimuli into a broader interpretive framework (Weick 2001) is essential for stakeholders to grasp the system’s emergent properties, such as evolving doctrines or codified norms, which influence outcomes over time. This is crucial in law, where collective behaviour and adaptive responses are continually shaped by feedback mechanisms (Ruhl et al. 2017). Meaning-making deepens understanding by linking individual motivations to system-wide impacts. It encourages evaluators to assess why certain interpretations or values matter in law and how they align with broader societal goals.

Secondly, ensuring meaningful participation emphasises empowerment within society. In legal contexts, meaningful participation requires careful consideration of multi-actor networks, where

diverse institutional actors and individuals navigate overlapping hierarchical and non-hierarchical structures. Evaluating the depth and quality of participation among judges, legislators, sustainability experts, and citizens involves not only assessing their involvement but also fostering agency and ownership in the evaluation process (Apgar et al. 2024). Evaluating participation among judges, legislators, sustainability experts, and citizens involves assessing their engagement while also fostering agency and ownership in the evaluation process (Apgar et al. 2024). The question of agency in sustainability transformation has been described as “one of the, if not *the*, burning questions of our time” (Teerikangas et al. 2021). Rather than focusing on individual agency, the emphasis is on emergent collective agency shaped by actor interactions. This does not negate individual significance but highlights the co-constitutive relationship between individuals and the collective. Within legal systems, integrating varied perspectives – often through participatory methodologies like systems mapping (Barbrook-Johnson and Penn 2022) – enables participants to visualize and contribute to a holistic view of the system.

Thirdly, establishing an iterative validation process and reflexivity are essential to accommodate the evolving nature of complex legal systems. Since legal systems function through constant feedback loops (e.g., legislative oversight, judicial review), an iterative validation approach enables ongoing reassessment and recalibration based on real-time insights and stakeholder input. This also enables the recognition of emerging path dependencies that constrain current structures and limit opportunities for change (Butler and Allen 2008). Huitema et al. (2011) applied this perspective to the assessment of policies meant to address climate change and concluded that fostering reflexivity is particularly important for this issue (e.g., Herrick and Sarewitz 2000). Set goals (e.g., a 40% CO₂ reduction by 2030) can quickly become outdated as scientific or societal consensus evolves. A more reflexive process fosters adaptive learning in complex systems, where evaluations must stay dynamic and responsive to shifts in legal norms, processes, and actors (Sala et al. 2015). Through iterative validation, the evaluation process adapts to emerging insights, ensuring that systemic impacts are accurately captured and continuously refined considering new information.

5 Conclusions and a complexity-sensitive research agenda for legal systemic change and evaluation

This article shows how viewing law as a complex-adaptive system can help identify and target legal interventions with the potential to accelerate expansive change toward sustainability. Recognising law as a complex-adaptive system expands the focus from broad framework changes to using strategic, targeted nodes in legal networks as the internal legal system levers to produce the legal system’s output levers. We have illustrated this with examples, from targeted legislative reforms to climate litigation. A key challenge in thinking of law as a complex-adaptive system is, however, that with traditional legal methodologies (interpretation, systematisation, comparison), information about the key nodes of *legal systems* is scarce and based on qualitative understanding and trial and error. This understanding does not enable a

quantitative or model-based identification of nodes, nor are legal scholars and practitioners trained to think in ways that achieve this.

A complexity perspective on legal systems requires applying complexity science to legal education and research. Identifying nodes in legal systems and assessing their impacts demand a broader shift in legal education, legal research and the adoption of, for example, computational methods to study the interconnections between legal components (actors and materials). Such work has already begun (Vivo et al. 2024) but is waiting for more widespread adoption in legal scholarship and practice. Expanding computational analysis, including Natural Language Processing and quantitative legal network analysis, could significantly enhance the identification of key legal systemic nodes for strategic intervention. Conventional legal methods can then be used to translate identification of nodes to knowledge concerning operational changes in legal provisions and case law, as well as procedural knowledge on where and by whom change can be initiated. Such a novel combination of perspectives and methods has the potential to promote considerable change in legal systems.

Harnessing legal complexity will also require a structured, iterative, multi-scale process to evaluate the impacts of targeted legal interventions on coupled systems of humans and nature. With significant advances in computing power (e.g., simulation modelling, machine learning, AI) and automated monitoring, the prospects for vastly improved multiscale governance are brighter (Garmestani et al. 2023). Current Regulatory Impact Assessment tools focus on simplistic framework-type legislative changes and rely on a linear theory of change, assuming laws directly drive intended social-ecological outcomes. Shifting to a complexity-sensitive approach requires new impact evaluation methods grounded in inter- and transdisciplinary collaboration (Castellani and Gerrits 2024). Evaluating systemic impacts requires a multifaceted approach integrating sense- and meaning-making, meaningful participation, and iterative validation. These evaluations must consider the complex interplay of institutional actors, norms, and processes shaped by systemic feedback mechanisms. Combined, these elements deepen understanding of complex legal dynamics, their governance and social-ecological impacts, and adaptive learning. They equip evaluators to drive legal change by targeting strategic nodes within legal systems, navigating evolving relationships and dynamics, and resisting oversimplification. Rather than reducing complexity, the focus should be on managing complexity effectively through integration, adaptive processes, and diversified governance structures. This shift requires legal frameworks that are not only flexible but also capable of iterative learning, ensuring regulatory approaches remain responsive to evolving social-ecological dynamics. Legal system complexity can thereby be harnessed to improve opportunities for a radical shift to sustainability.

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Table 1.

	How scientists focusing on sustainability view law?	How traditional legal scholarship views law?	How complexity-science inspired legal scholarship views law?
What is law?	Law as a (legislative/treaty) <i>instrument</i> regulating specific issues.	Law as a system of <i>legal sources</i> (legislation, court rulings, soft law etc.) and <i>institutional actors</i> passing, interpreting and implementing them.	Legal systems are complex adaptive systems that are composed of networks of institutions (courts, legislatures, agencies) and instruments (laws, regulations, judicial decisions).
Who can enact and change the law?	Can be enacted or changed if there is sufficient <i>political will</i> .	<i>Institutional actors with the legal mandate to do so</i> : states, legislatures, courts. Contingent on political will on the legislative aspects, but not on the judicial aspects. Also: not many/all legislative questions are politically deliberated at any given time (e.g., constitutional, or questions outside national competence).	Changing the legal system necessitates modifying the attractor landscape. This might significantly influence the alteration of interaction patterns. Identifying and analysing these attractors can assist policymakers in designing incentives and sanctions that create a sticky attractor landscape for sustainable behaviours, thereby reducing the likelihood of reverting to unsustainable practices.
How does law impact society?	Has <i>direct and linear</i> impact on society if changed.	<i>Depends on context</i> . If specific regulation, can have direct and linear impact. If regulation focusing on broader topics, then new/changed legal sources enter a space crowded with existing instruments and impact-pathways. Typically, impact would be considered linear also here if the legal source in questions is sufficiently specific, uses binding language and seeks to regulate the key actors and dynamics.	Changes in legal sources do not necessarily yield large legal or societal impact (e.g., the EU Green Deal). At the same time, small interventions (e.g., climate litigation) can have disproportionately large impact. This phenomenon can be explained by the presence of dissipative structures within complex systems, which can induce abrupt and unpredictable shifts in the system's trajectory. These shifts often produce outcomes that are not proportionally related to the initial stimuli.
What methods are used to understand legal change and its societal impact?	Typically, <i>no rigorous methods</i> as this is not considered to be a scientific question.	Legal change is analysed using <i>doctrinal methods</i> (sources of law and rules of interpretation). These are done in the context of established legal principles related to the topic. Impact on society is not analysed with rigorous methods; <i>at best traditional qualitative</i> (e.g., interviews) and <i>quantitative</i> (e.g., statistics; questionnaires) methods are used.	For legal change: Quantitative social and legal network analysis; statistical inference. For impact: complexity science inspired Delphi's, co-creation and other methods. For legal reform: Quantitative social and legal network analysis; agent-based modelling; systems mapping (Causal Loop Diagram). For impact: impact pathways, non-linear change theory, cascading effects analysis, outcome harvesting.

Table 2.

ELEMENTS	TRADITIONAL REGULATORY IMPACT ASSESSMENT APPROACH	COMPLEXITY- SENSITIVE IMPACT EVALUATION APPROACH
Causal assumptions	Linear, impact chain (logic model)	Non-linear, cross-scale and cascading effects
Intervention Logic	Predetermined and fixed	Adaptive and evolving
Focus	Narrow (single law)	Broad (legal and societal systems)
Evidence base	Explicit knowledge	Both explicit and tacit
Participation	Hearings, comments	Co-creation, sensemaking
Externalities	Not identified	Identified
Verification	Achieving results	Understanding patterns
Type of Change	Transition	Transformation