REVIEW

On the social-ecological systems (SES) diagnostic approach of the commons: Sharing, cooperation, and maintenance

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Abstract

The future of human civilisation is dependent upon linking the prosperity of people and the planet. This paper provides a balanced survey of relevant studies on the social-ecological systems (SES) integration, organised in the analytical structure of institutionalised governance process of enduring human cooperation on shared common resources and environment. It takes a critical look at the emerging SES literature on complexity and uncertainty that attempts to capture the dynamics of change over time and across scale. The final section looks into some of the major challenges ahead—application of various valuation methods without proper location of diverse values in the SES model, interdisciplinary gap to capture the SES interactions, and obstacles of practising SES in reality. It aims to contribute to the broader significance by identifying 2 interconnected research gaps: systematic understanding of interactions among the SES integration (diagnostic explanation), and the development of appropriate scalable and integrated strategies for solving complex problems under SES integration (policy intervention).

Author summary

The Earth has been around for 4.5 billion years, and today, human activities have become a significant force in altering the Earth system, which is rapidly changing the planet, making environmental issues a prominent concern. The social-ecological systems (SES) theory has substantially facilitated us to better understand the world we live in as a holistic entity. As the human systems evolve rapidly, however, the theory must adapt to these changes and scrutinise the design of human systems. In the new stage of Anthropocene, we must focus on the complex and dynamic interactions between man and nature, as well as the power structure of governance designed by man, in order to achieve a sustainable future of the human species. Nevertheless, the ultimate mission for mankind, not even for the planet we inhabit, is to survive drastic transitions essentially caused by mankind. We need to shift our way of thinking from seeking for the best practice to exploring for the best fit.

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Introduction

The future of human civilisation is dependent upon linking the prosperity of people and the planet. Interestingly enough, this linkage also imposes the most fundamental dilemma—growth (human development) versus environment and resources (nature conservation). The discussions on complexity of social-ecological changes and related governance approaches signalised an emerging direction of the cross-scale and cross-system research on social-ecological systems (SES) integration. In recent decades, interdisciplinary sustainable development studies have attempted to investigate the interdependence and coevolution of human societies and natural ecosystems, both intertemporally and spatially, fully articulated in the SES integration theory. The SES framework has endeavoured to trace the parallel interactions between human systems (actors) and natural systems (resources) [1,2]. It was important because the theory illustrated a simple mechanism of how social system of governance and natural resource system with distractible resource units interact with each other. However, SES theory was also strongly criticised for its incapability to analyse cross-scale interactions given its limited explanatory power to interpret above-local systems. The neglection of capturing the dynamics of the cross-system interactions also hugely undermined its analytical framework. Another shortcoming is to incorporate the enriched dimension of human development, which has long developed away from narrow measurement of GDP, and the dimension of biophysical environment, representatively demonstrated in 9 planetary boundaries [3]. Globalisation with several mega-trends sits in the centre of SES interaction, particularly in resilience, vulnerability, and adaptation of environmental change [4]. However, SES cannot flexibly reflect these mega-trends under globalisation. Drawing the whole picture of such complex, dynamic, and uncertain interdependence and coevolution of SES is extremely challenging.

An integrated analytical framework

There is a great need to build an integrated SES framework in order to consolidate various aspects, theories, and models for comprehensive analysis [5]. This is essential for filling the gap of furnishing currently existing evidences and knowledge into a unified framework for better understanding on human nature systematic dynamics and for informing intervention designs of decision-making and implementation that generate changes and transformation to the systems.

Variables

The studies on the common-pool resources and governance systems researched extensively on the attributes of resource systems and governance systems, or in another word variables in respective system. For instance, the variables include resource system boundaries and sizes, political system, and demographic features. The direct causal links between system variables and system mechanisms are self-evident [6]. The mechanisms are processes of dynamically changing relationship among variables [7]. System structure, on the other hand, is more complicated. System structure is the arrangement of the relations between the variables as the parts that formulate the complex systems, whereas mechanisms are methodical processes that have variables working together as their parts. Variables being categorised into system organisational carriers, operation, and rules can determine the system structure in various ways. As shown in Table 1, SES variables can be represented by multiple tiers, ranging from systems variables through fourth-tier thresholds. These variables induced shifts and shocks either within the same tier of a subsystem or between different tiers across systems. In other words, a subsystem is capable of shocking another subsystem as well as the major system as a whole.

Table 1. Social-ecological systems variables.

Systems variables	First tier variables	Second tier variables	Third tier variables	Fourth tier variables/ thresholds
Resource systems	*Resources*	Sector	e.g., water, forests, pasture	
		Clarity of boundaries		
		Size	Area	
			Volume	
		Infrastructure		
		Productivity		
		Predictability of dynamics		
		Storage capacity		
		Equilibrium properties	Recharge dynamics	
			Recharge rate	
			Number of equilibria	
			Feedbacks	Positive
				Negative
		Location		
	Resource units	Unit mobility		
		Interactions among the units	Strong to weak	
			Predatory or symbiotic	
		Replacement rate		
		Distinctive markings		
		Economic value		
		Size	Large to small	
			Trophic level	
		Distribution	Spatial heterogeneity	
			Temporal heterogeneity	
Governance systems	*Governance*	Rules	Operational rules	
			Collective choice rules	
			Constitutional rules	
		Property-rights regime	Private	
			Public	
			Common	
			Mixed	
		Network structure	Centrality	
			Modularity	
			Connectivity	
			Number of levels	
	Actors	Group size: number of the users		
		Socioeconomic attributes	Economic	
			Cultural	
		History of use		
		Location		
		Leadership		
		Social capital		
		Knowledge		
		Resource dependence		
		Technology used		

(*Continued*)

Table 1. (Continued)

Systems variables	First tier variables	Second tier variables	Third tier variables	Fourth tier variables/ thresholds
	Action situations	Process	Monitoring	Environmental
				Social
			Sanctioning	
			Conflict resolution	
			Provision	Informational
				Infrastructural
			Appropriation	
			Policymaking	
		Interactions	Harvesting levels of diverse users	
			Information sharing among users	
			Deliberation processes	
			Conflicts among users	
			Investment activities	
			Lobbying activities	
		Outcomes	Social performance measures	Efficiency, equity, accountability
			Ecological performance measures	Overharvested, resilience, diversity
			Externalities to other resource systems	
Earth and nature system	*Climate change*	Atmospheric CO2 concentration ppm	Loss of polar ice sheets	
			Regional climate disruptions	
		Energy imbalance at top-of-atmosphere, Wm−2	Loss of glacial freshwater supplies	
			Weakening of carbon sinks	
	Change in biosphere integrity (rate of biodiversity loss)	Genetic diversity	Extinction rate E/MSY = extinctions per million species-years	
		Functional diversity	Biodiversity intactness index (BII)	
	Stratospheric ozone depletion	Stratospheric O3 concentration	Severe and irreversible UV-B radiation effects on human health and ecosystems	
	Ocean acidification	Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite	Conversion of coral reefs to algal-dominated systems	
			Regional elimination of some aragonite- and high-magnesium calcite-forming marine biota	
			Slow variable affecting marine carbon sink	
	Biogeochemical flows	P Global: P flow from freshwater systems into the ocean		
		P Regional: P flow from fertilisers to erodible soils		
		N Global: Industrial and intentional biological fixation of N		
	Land-system change	Global: Area of forested land as % of original forest cover		
		Biome: Area of forested land as % of potential forest	Tropical: 85% (85%–60%)	
			Temperate: 50% (50%–30%)	
			Boreal: 85% (85%–60%)	
	Freshwater use	Global: Maximum amount of consumptive blue water use (km3yr–1)		
		Basin: Blue water withdrawal as % of mean monthly river flow		
	Atmospheric aerosol loading	Global: Aerosol optical depth (AOD), with regional variation	Human health effects	
			Interacts with climate change and freshwater boundaries	
		Regional: AOD as a seasonal average over a region	Disruption of monsoon systems	

(*Continued*)

Table 1. (Continued)

Systems variables	First tier variables	Second tier variables	Third tier variables	Fourth tier variables/ thresholds
	Introduction of novel entities	No control variable currently defined	Thresholds leading to unacceptable impacts on human health and ecosystem functioning possible but largely unknown. May act as a slow variable undermining resilience and increase risk of crossing other thresholds	
	Ecosystem	Ecosystems	Boundaries and categories	
			Hierarchy, complexity, structure, functioning	
			Evolution and biocultural diversity	
			Ecological efficiency	
		Ecosystem services	Supporting services	
			Provisioning services	
			Regulating services	
			Cultural services	
Social systems	*Economic development*	Economic growth	GDP	
			GNI per capita	
			Imports and exports	Balance of payments
		Efficiency	Production	
			Consumption	
		Employment	Labour and productivity	Unemployment rate, output per worker
	Human development	Poverty	Multidimensional, across regions	
		Decent living standard	Inequality	Income, wealth
				Opportunity
				Gender
			Liveable cities and communities	
			Access to affordable and clean energy	
			Clean water and sanitation facilities	
		Long and healthy life	Life expectancy	
			Health care	
		Knowledge	Education	
			Social capital	
			Human capital	
			R&D investment	
	Political system	Political stability	Government stability, tensions, and conflicts	
		Cooperation and collaboration	Shared common goals, strengthening resource mobilisation, capacity building	
		Inclusive institutions	Nondiscriminatory laws and policies, participation of global governance	
		Regulatory quality	Price control, investment freedom	
		Government effectiveness	Quality of bureaucracy, policy instability	
		Absence of violence	Armed conflict, security risks	
		Rule of law	Enforceability of contracts, judicial fairness	
		Control of corruption	Diversion of public funds, public trust, corruption	
		Voice and accountability	Democracy, political rights, transparency	
	Technology and innovation	Knowledge accumulation	Incremental, purposeful knowledge accumulation	
		Disruptive breakthroughs	Fundamental transformation	
		Self-organisation	Knowledge, methods, and practices	
			Industry, innovation, and infrastructure	
		Transfer and diffusion	Learning process and network	

This table was compiled by the author based on a number of different studies [8–13].

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The governance system in Table 1 consists of governance, actor, and action situation, which radically differs from Ostrom's IAD framework. Governance is fundamentally a complex and dynamic mechanism facilitated by various institutions and organisations, all of which are embedded in a particular value system, to promote collective action for the common good. By highlighting the polycentric interactions of numerous institutions and actors with distinct powers and structures, governance deconstructs the simplistic demarcation of the state, market, and society. Instead of being the simple dichotomy of top-down versus bottom-up approaches, the governance system is complex, diverse, dynamic, and interrelated. On the other hand, governance is a process with a clear a priori objective and a post hoc outcome of achieving the good governance. The actions and counteractions that generated by the behaviours of various actors and their respective outcomes comprise the process of governance. It is a process of negotiations and compromises aimed at resolving conflicts of interest, as well as a collective action process centred on the long-term common good.

System structure

The system is composed of the mechanisms of operation under certain institutions as the rules for operation, on the basis of the organisation as the carrier. Institutions are "software," organisation is the "hardware," and mechanism is the actions and interactions. Institution can be understood as the rules and conventions to regulate human actions with shared beliefs and values under the governing process of social systems, and institutional change is a dynamic process of balance equilibrium of operation [14]. Policies are measures adopted to deal with the public affairs, to accommodate conflicts of interests. Policies are structured within the institutional process of change and transformation.

Mechanisms

The general theory of evolution holds that both the biological world and human society follow the evolutionary principle of variation (disturbance)–selection (adaptation)–retention (stabilisation). Some applied generalised Darwinism as their theoretical foundation by adopting the general evolutionary mechanisms, while others used complexity theory to address the issues of self-organising mechanism. As shown in Fig 1, all units and subsystems interact with each other differently depending on the information they receive and the environment to which they belong, within the boundaries of overall system framework [15]. When changes and coevolution (i.e., interactive changes and feedbacks) constantly occurred, the systems would adjust to the changing dynamics, and vice versa, the units and subsystems would also respond to the system adjustment [16].

Similar to the evolutionary mechanism of variation–selection–retention, SES resilience literature sees the emergent process of system dynamics as disturbance–adaptation–stabilisation [17–19]. Disturbance triggers change of rules in use, attributes of social systems and ecological systems, and system structures, while adaptation adjusts to these disturbances, it can be intentional (deliberate change for positive transformation) or unintentional (evolutionary self-organisation). The system stabilisation may be either a new state of balance (transformation) or a change of state (drift). For instance, technological innovation and diffusion can bring disturbance to the systems by changing the rules in use, such as the way in which information is shared, or by altering the attributes of production process, and by reshaping traits of natural systems [20]. On the other hand, disturbance of systemic change may urge for technological innovation, such as climate change. Nevertheless, it is true that self-organisation does not defy the conscious choice of rationality. This is an important point to keep in mind. Incorporating technological innovation in SES evolutionary process may lead some systems transforming across tipping points and regime shifts, or transitioning within the scope of incremental change. Disruptive technology, for instance, represents transformation to a new state, while gradual technological advancement may lead to incremental changes before the threshold.

Practising the SES framework

While there is complexity and uncertainty in the evolution of system dynamics, this complexity and uncertainty precisely provide the space for policy intervention. Self-organisation theory of CPRs is applicable to smaller-scale socio-ecological systems, such as irrigation, fisheries, and forests, but often encounters challenges when addressing socio-ecological systems at regional or even global scales. First, coupled SES at the regional scale extend beyond the borders of the nation-state, making it difficult to distinguish internal and external factors within the framework of institutional analysis. Second, institutional provision at the regional scale is dependent on less binding non-sovereign national governmental organisations and institutions. This section proposed a design strategy for SES framework-based policymaking.

Goal

The goals of sustainability of SES integration can be presented in, at least, 3 different ways—targets, scenarios, and pathways. Targets are quantitative and qualitative goals, a series of indicators to achieve the preferred equilibrium of SES. For instance, the UN Sustainable Development Goals (SDGs) elaborated all goals in multiple levels of targets. Some studies tried to understand the synergy and interactions among 17 SDGs to avoid targets being listed independently in isolation [21,22]. Scenarios are essentially used in climate change research for describing alternative futures with plausible descriptions in key areas. Two distinctive features of scenarios approach are its focus on long-term impact and its systematic analysis. Pathways, like the Representative Concentration Pathways (RCPs), are understood as "a parallel process" instead of sequential scenarios approach [23]. For instance, the Shared Socioeconomic Pathways (SSP) illustrated the main socioeconomic drivers for potential change of environment and impacts to climate, in which climate modelling and integrated assessment modelling of socioeconomic impacts are conducted simultaneously. Consolidating different goals for SES integration can be realised by selecting key variables and formulating their relationships [24].

Intervention design

Decision-making is carried out in 3 interweaved domains, policymaking, public awareness, and investment. Decision-making is all about accommodating conflicts of interests and choosing synergies and trade-offs for the common good. The 2 key aspects of an institutionalised governance are promoting collective action for the common good and maintaining such collective action [8,25]. The process of institutionalised governance can be seen as the actors with a great variety of capability, accountability, and power structure generating corresponding actions, as exhibited in Fig 2. On top of that, the political system of a given governance process determines both decision-making and decision implementation. The political context set general rules for decision-making. In the cases of China and the United States tackling similar environmental issues, their distinctive political systems determined rather different course of policymaking. When the Chinese system is dominated with central state planning and irregular crisis scanning and policy responses, the American system is centred with legal practices and multilevel federal governance [26]. Both systems presented advantages in some areas and disadvantages in others, and both systems obtained profound societal roots and historical path dependence. Political context also influences the policy diffusion, level of policy ambiguity, and complexity substantially.

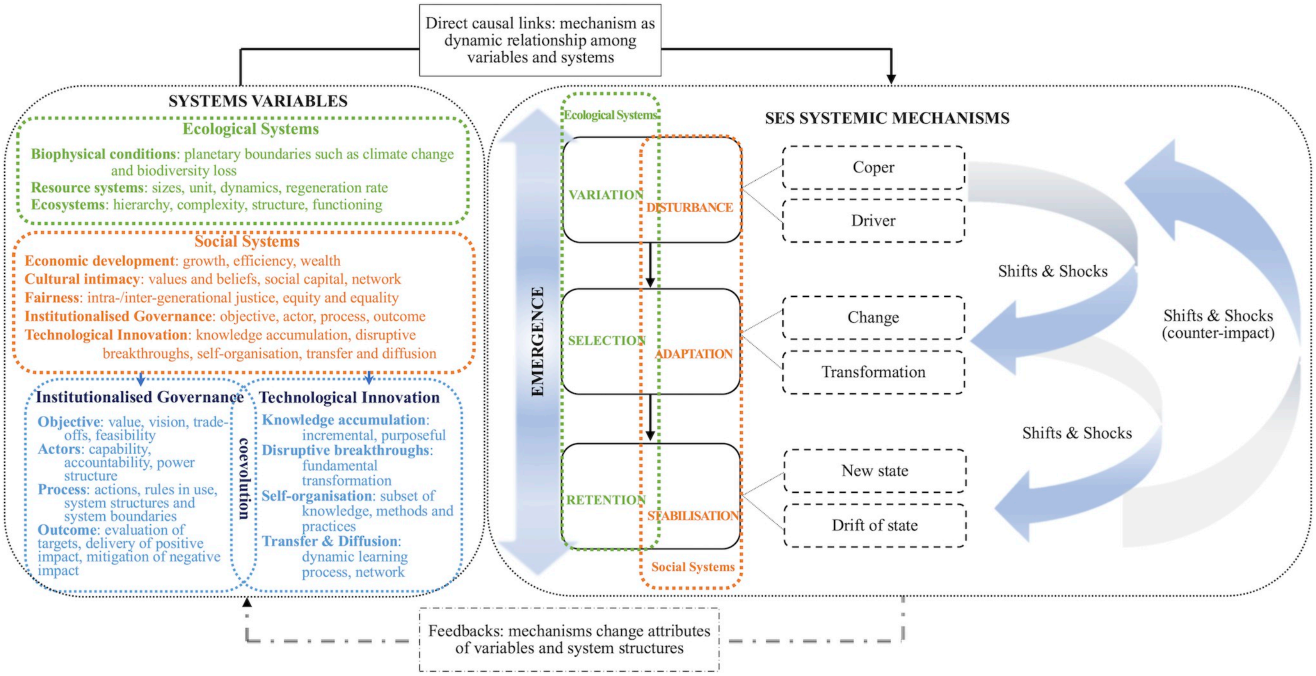

Fig 1. Technology and institution under the social-ecological systems framework.

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Assessment and monitoring

When policies are formulated and delivered, constant monitoring and assessment are crucial. There are various ways to assess policy, from effectiveness analysis to indicator system [6]. Up until present, the focus is on which criteria contributed to policy effectiveness and which indicators effectively monitor policy implementation. How policy processes and its larger institutionalised governance framework may impact on policy effectiveness, however, remained poorly understood. There are many aspects of policies to be examined and their impact to be measured. Policy horizons and agendas set the overall framework of the purposive course of policy actions require less frequent visits than activities on the ground, in order to maintain stability of policy agenda [27].

Challenges ahead

What value matters?

Does the assignment of values to SES contain any inherent bias? Can they reflect the human diversity of moral pluralism and cultural relativity? Value is the regard that something is held to deserve, and hence, it assists policymakers in establishing societal goals and designing social engineering for trade-offs. There are various kinds of values—instrumental, intrinsic and relational, alternatively cultural, economic and natural values, the list can go on. Nevertheless, values are defined by their dynamic interrelations of compatibility and conflict [5].

The exploration of nature's value reveals the dialectical relations between man and nature, which is mutually constitutive and coexisting. It avoids the anthropocentrism's usurpation of man's absolute subject status over nature, as well as the ecocentrism's return to the absolute wilderness. Anthropocentrism advocates the subject status of human and supports that the value of nature is dependent on human, and thus, the nature has no independent value without human involvement. However, the process of economic growth in human societies excessively promotes consumerism and materialism, which inevitably leads to the extreme depletion of natural resources and ecological environment, exceeding nature's carrying capacity and its self-recovery function. Ecocentrism, on the other hand, holds that the ecological crisis is precisely the result of human's egocentric excessive plundering and intervention in nature, neglecting the value of nature itself, and destroying the original equilibrium of nature. Humans are merely a link in the ecological chain, as it advocates that natural ecology should be regarded as an organic entity that includes. Ecocentrism places a strong emphasis on the intrinsic value of nonhuman natural life, and humans no longer hold the privilege over other natural beings. Indeed, this is a profound self-reflection of anthropocentrism. However, value is a judgement and evaluation of the object by the subject in terms of its usefulness to the subject, and to give nature self-value would be to recognise its subject status, that would require nature to have free will in order to evaluate the object, which is obviously not possible. Regardless of how much we debate, it is impossible to escape the perspective of human thinking. Even the judgement that nature possesses intrinsic value and is independent of man, is a reasonable judgement made by man. Thus, humans are not the only holders of values, but they are the only beings capable of making value judgements.

Valuation is the judgement of the values, and therefore, the guideline for the intervention design. Valuing the nature has long been acknowledged as a step forward in assessing the invisible values of the environment and its resources. Ecosystems, for instance, provide a variety of services that are of fundamental importance to human well-being and therefore they need to be evaluated—in forms of natural capital, stewardship, or relative scale to the GDP growth [28]. Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) proposed to move from the economic-dominated valuation to the pluralistic valuation by incorporating values of the nature such as biodiversity and ecosystems of life, values of good quality of life as human well-being, and values of the nature's contribution to people such as the ecosystem services [29].

In the real world, however, values and valuations of the SES are not neutral due to the constraints imposed by different political and economic systems. Also, values appear to be hard to travel across cultures at times. While universal values and global values are effective in formulating a global vision of the common good, they are also ineffective in pushing such vision down to the ground. To date, relatively few attentions have been paid to the challenges of cultural differences and the clash of global visions. To think and act globally remains a difficult task to achieve.

Finally, valuation is also a process of assessing potential trade-offs. Valuation is to elicit the value of certain domain of the SES systems [30]. Valuation reflects a process by which the particular value elements of the nature can be obtained through different measurements to align different policy targets. However, there is a gap between integrating diverse values and aligning different policy targets. Value trade-offs can also highlight the interlinkages of behaviours, intentions, norms, and social-political processes. Recognising the system structures, processes, and values underpinning sustainability outcomes requires a significant reconfiguration and research effort into how sustainable development, resilience building, and other sustainability investments are monitored.

The interdisciplinary gaps

The institutionalised governance process framework built in the SES model can integrate dynamics of feedback, driver, and regime shift. But the knowledge gaps of SES interactions require fundamental interdisciplinary research. The epistemological language jointly shared across disciplines as the first step of interdisciplinary collaboration is challenging enough.

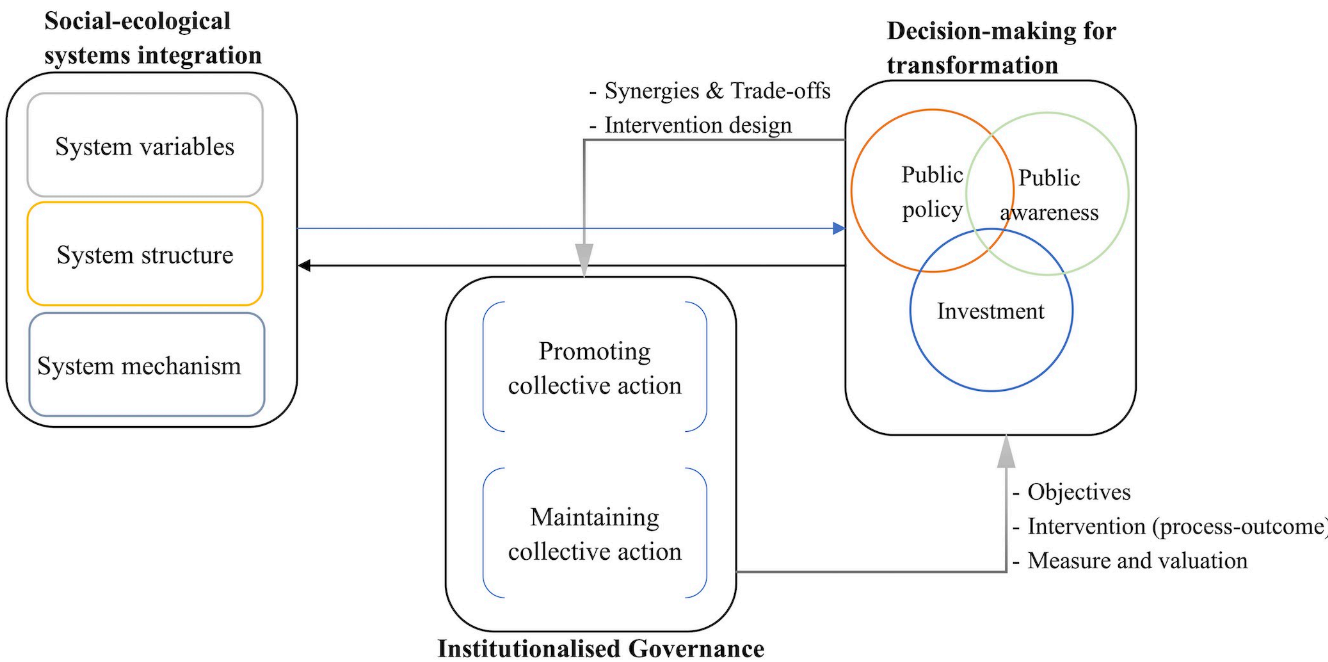

Fig 2. Social-ecological systems intervention process.

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Addressing SES issues on different scales is another big gap. Large-scale biophysical models like the planetary boundary model are difficult to be downscaled to local communities. Integrating evidence and data from various scales causes more confusion than understanding, not to mention the limited explanatory strength of theory or model under different social contexts. Majority illusion refers to a social psychological circumstance that individuals may suffer from limited information in their social network for decision-making when they are lacking holistic information overall, they may think their preferences and standing points are representing the majority of all people. As a result, it is necessary to investigate the social network surrounding individuals using both social psychology and group theory, in order to understand the complexities of the decision-making process. Also, disconnection between downscaling of SES modelling and upscaling of case studies is also problematic—there are studies concentrate overwhelmingly on empirical case studies, but limited attempts to draw links among them to show the whole picture of coevolution. There is also a big lack of multilevel analysis to integrate different institutional contexts and historical discourses.

Moreover, compatibility of various methodologies imposes another fundamental difficulty for the SES theory. Conceptual focus only provides a snapshot in time and does not illuminate processes of institutional change. In many cases, the controllable factors that explain causal relation are selected for analysis so that solutions can be prescribed. Although there may be a variety of causes for a given problem, the uncontrollable factors shall not be simply disregarded. SES tends to apply interdisciplinary methodologies to avoid these problems. Prediction modelling to forecast a change or trend, analysing uncertainty with limited information available, and experimenting human behaviour are all useful methods for SES studies. The most popular tool, however, is meta-analysis, which is a key tool to facilitate rapid progress in science by quantifying what is known and identifying what is not yet known. Evidence synthesis should become a regular companion to primary scientific research to maximise the effectiveness of scientific inquiry. Scientists have collected data in individual studies, based on observations and experimentation. The introduction and implementation of meta-analytic techniques was the first large-scale, coordinated effort to collect and synthesise preexisting data to determine patterns, make predictions, reach generalisations, and make evidence-based decisions. Methodological challenges also include moving from causalities to complexity. Technology is the extension of human capabilities beyond biological limits, which make it possible with big data and new technology available. All of these instruments, however, can only be effectively useful if an integrated analytical framework is capable to cope with a world in transition.

On the other hand, institutional analysis provides an effective tool to link large-scale Earth system studies and local community resource management. SES model presents a logic chain between human behaviour and ecological systems—using institutions to promote commitment for collective action and nurture long-term trust for the common good. Methodologically, institutional analysis can bridge agent-based modelling and larger biophysical models by narrating an institutionalised governance process with feedbacks, dynamics, and evolutions.

Obstacles in practice

The Earth has been around for 4.5 billion years, and all of the milestones in its history are the turning points that have shaped this planet. With 8 billion people living on Earth by 2022, the planet has reached its limits in terms of natural resources such as land and water that the rapidly growing population need to consume. The Anthropocene is regarded as a critical epoch in which human activities alter the boundaries of the Earth system and drive the changes of the natural environment. It marks that the Earth has entered an unprecedented new geological era in which human and natural processes interact. In the geological scale, the human existence is merely a "flash of moment," but it is in this moment that the large-scale impact of human activities on natural ecosystems occur. As a new geological force, human activities can match the Earth's natural forces in terms of strength and global reach, and with the progress of human development, this impact grows and becomes more profound. At present, human activities have become a significant force in altering the Earth system, which is rapidly changing the face of the planet, making environmental issues a prominent concern. In this new stage of Earth history, human society is required to understand this planet on which it resides and to achieve sustainable development of the human species.

Transforming the world for a sustainable future remains a challenge, and it calls for investigation on strategies of incorporating systemic SES thinking into everyday decision-making. Down to the Earth, practising the SES model faces various challenges. SES model represents a so-called conceptual model with limited potential to incorporate empirical evidence, to apply in practice and to inform the policy process. Environmental management systems have evolved along with the scientific exploration of relevant evidences and knowledge [31]. There is lagging process for these management systems to be adapted to new paradigms. Applying SES model in practice may need to challenge previous paradigm path-dependence and also overcome the institutional limitations or even absence. SES application means addressing environmental issues at much broader scales, which can present practical difficulties to implement. Therefore, building engagement between science and policy is vital.

SES model under different sociocultural contexts is another obvious shortcoming when it comes to the less straightforward sociocultural features of invisible norms and values. One question that needs to be asked is whether the SES model works well in distinctively different sociocultural settings, for instance, as abovementioned, in the US and in China. Chinese governance approach is institutionalised on strategic planning and crisis scanning with high flexibility, while the US approach is law-centred practices within a federal political system [26]. The key to governance is the coordination and power structure, i.e., who drives and who holds back changes and transformations. Therefore, more systematic study would be required to identify how SES model can work in vastly distinctive societies with different power structures and coordination.

Is the self-governance the third way? Alternatively, can polycentric governance scale up sustainability? In numerous societies, such as India, South Africa, and many others, polycentric governance has been practised for a very long time, but it has only been formally defined in academic terminology until recently [32–34]. Polycentric governance has been justified as the optimal governance approach for resources sharing around the world. However, the hybrid governance structure comprised of various stakeholders, such as the state, market, self-governing communities, NGOs, etc., has been misunderstood when applied to various cases. The confusion was caused by the content and structure of polycentric governance. The arrangements of the state and market were demonised more often than usual by the extreme line of thought. Obsession with self-governance by non-state actors at community-level led to a concentration on community-level cooperation and externalisation of other institutions and systems. Many studies largely ignored the role of the state and the market, being rejected as the other 2 ways, self-governance became the third and arguably "optimal" way. For which, it turned a blind eye towards hybrid solutions representing the real world.

Governance typically signifies the governing power of the state, which was originally associated with government. Therefore, discussions on governance are constantly taking place "within the state, by the state, without the state, and beyond the state" [35]. Ostrom once said: "the theory of collective action is the core of the justification of the state" [36]. There are needs of a higher-level state, "to threaten to impose a solution. . .to provide a source of relatively neutral information. . .to provide an arena for negotiating. . .to help monitor compliance and sanction defection in implementation" [37]. Identifying a series of adaptive institutions that can nurture trust and long-term cooperation is essential for the institutionalised governance process. The adaptive capability of certain institutional framework is equally, if not more, important than polycentricity to improve the system resilience. Another issue that is often neglected in the discussion of the SES model and the commons, is who designs the policy intervention. Is decision-making dominated by technocrats or politicians, or by the general public? Is the technocracy up against democracy? Although this is a topic beyond the discussion in this paper, it stands as one of the key aspects of a sustainable future.

The generalisation of humanity as a whole does not reject imbalanced dominance and power distribution within human societies. Rethinking the depoliticised interpretation of ecological issues demands politicising the interpretation of ecological issues. Investigation on the ecological problems caused by the logical dimension of power is needed, the complex power relations between capital, government, and the public in real cases of ecological damage, and how to transcend the path of ecological governance under the hostage of power. It would be idealistic to solely initiate sustainable development plans through existing ecological modernisation programmes, without modifying the underlying structure of institutional mechanisms.

Although the scientists' discussions on the limits of the planet and the Anthropocene clearly point to a link between the ecological crisis and global inequality, the ecological factors that lead to global inequality are not reflected in any of these models they constructed. In this regard, is it human beings as a species or man in the abstract who are primarily responsible for the ecological crisis, or is it the responsibility of those who have contributed to the destruction of humanity and the destruction of nature? Should the responsibility for the ecological crisis be found in the social relations that contribute to human destruction and the destruction of nature? The answers differ and so do their implications [38]. Taking these factors into account, only a scientific diagnosis, especially one that incorporates a socio-political component, can both draw people's attention to the problem and enlighten human societies about the contradictions and preconditions of the sustainable transformation. Nonetheless, the context variables representing socio-political systems impetrate further research to identify the determining factors in vastly diverse political systems [26,39,40].

In general, the SES theory facilitated a deeper understanding of the world as a whole. However, as the human systems are changing rapidly, the theory has to adapt to these changes and to scrutinise on the design of human systems. Nonetheless, the ultimate mission for humanity, not even for the planet people reside, is to survive drastic transitions essentially caused by mankind. The line of thought must shift from pursuing the best practice to exploring for the best fit, as Ostrom argued decades ago—"going beyond panaceas" [1].

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References

1. Ostrom E. A diagnostic approach for going beyond panaceas. Proc Natl Acad Sci U S A. 2007; 104 (39):15181–15187. https://doi.org/10.1073/pnas.0702288104 PMID: 17881578
2. Ostrom E. A general framework for analyzing sustainability of social-ecological systems. Science. 2009; 325(5939):419–422. https://doi.org/10.1126/science.1172133 PMID: 19628857
3. Rockström J, Steffen W, Noone K, Persson Å, Chapin FS, Lambin EF, et al. A safe operating space for humanity. Nature. 2009; 461(7263):472–475. https://doi.org/10.1038/461472a PMID: 19779433
4. Young OR, Berkhout F, Gallopin GC, Janssen MA, Ostrom E, Van der Leeuw S. The globalization of socio-ecological systems: an agenda for scientific research. Glob Environ Chang. 2006; 16(3):304–316.
5. Reyers B, Folke C, Moore ML, Biggs R, Galaz V. Social-Ecological Systems Insights for Navigating the Dynamics of the Anthropocene. Annu Rev Env Resour. 2018; 43(43):267–289.
6. Reyers B, Stafford-Smith M, Erb K-H, Scholes RJ, Selomane O. Essential Variables help to focus Sustainable Development Goals monitoring. Curr Opin Environ Sustain. 2017;26–27:97–105.
7. Ryan N, Sudarshan A. Rationing the commons. J Polit Econ. 2022; 130(1):210–257.
8. Ostrom E. Do institutions for collective action evolve? J Bioecon. 2014; 16(1):3–30.
9. Poteete AR, Janssen M, Ostrom E. Working together: collective action, the commons, and multiple methods in practice. Princeton, NJ: Princeton University Press; 2010.
10. Folke C. Resilience: The emergence of a perspective for social–ecological systems analyses. Glob Environ Chang. 2006; 16(3):253–267.
11. Rocha JC, Peterson GD, Biggs R. Regime shifts in the anthropocene: drivers, risks, and resilience. PLoS ONE. 2015; 10(8):e0134639. https://doi.org/10.1371/journal.pone.0134639 PMID: 26267896
12. Steffen W, Richardson K, Rockstrom J, Cornell SE, Fetzer I, Bennett EM, et al. Sustainability. Planetary boundaries: guiding human development on a changing planet. Science. 2015; 347(6223):1259855. https://doi.org/10.1126/science.1259855 PMID: 25592418

13. Rockstrom J, Steffen W, Noone K, Persson A, Chapin FS III, Lambin EF, et al. A safe operating space for humanity: identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue Johan Rockstrom and colleagues. Nature. 2009; 461(7263):472–476.
14. North DC. Institutions, institutional change and economic performance. Cambridge: Cambridge University Press; 1990.
15. Liu J, Dietz T, Carpenter SR, Alberti M, Folke C, Moran E, et al. Complexity of coupled human and natural systems. Science. 2007; 317(5844):1513–1516. https://doi.org/10.1126/science.1144004 PMID: 17872436
16. Klapwijk MJ, Boberg J, Bergh J, Bishop K, Björkman C, Ellison D, et al. Capturing complexity: Forests, decision-making and climate change mitigation action. Glob Environ Chang. 2018; 52:238–247.
17. Zhang Z, Liu Y, Wang Y, Liu Y, Zhang Y, Zhang Y. What factors affect the synergy and tradeoff between ecosystem services, and how, from a geospatial perspective? J Clean Prod. 2020; 257:120454.
18. Laspidou CS, Mellios N, Alexandra S, Kofinas D, Papadopoulou MP. Systems thinking on the resource nexus: Modeling and visualisation tools to identify critical interlinkages for resilient and sustainable societies and institutions. Sci Total Environ. 2020; 717:137264. https://doi.org/10.1016/j.scitotenv.2020.137264 PMID: 32092809
19. Rana P, Miller DC. Explaining long-term outcome trajectories in social-ecological systems. PLoS ONE. 2019; 14(4):e0215230. https://doi.org/10.1371/journal.pone.0215230 PMID: 30986266
20. Zhang Y. The map is not the territory: coevolution of technology and institution for a sustainable future. Curr Opin Environ Sustain. 2020; 45:56–68.
21. Sachs JD, Schmidt-Traub G, Mazzucato M, Messner D, Nakicenovic N, Rockström J. Six Transformations to achieve the Sustainable Development Goals. Nat Sustain. 2019; 2(9):805–814.
22. Biermann F, Kanie N, Kim RE. Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals. Curr Opin Environ Sustain. 2017;26–27:26–31.
23. Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, van Vuuren DP, et al. The next generation of scenarios for climate change research and assessment. Nature. 2010; 463(7282):747–756. https://doi.org/10.1038/nature08823 PMID: 20148028
24. Stafford-Smith M, Griggs D, Gaffney O, Ullah F, Reyers B, Kanie N, et al. Integration: the key to implementing the Sustainable Development Goals. Sustain Sci. 2017; 12(6):911–919. https://doi.org/10.1007/s11625-016-0383-3 PMID: 30147763
25. Bodin O. Collaborative environmental governance: Achieving collective action in social-ecological systems. Science. 2017; 357(6352):eaan1114. https://doi.org/10.1126/science.aan1114 PMID: 28818915
26. Young OR, Guttman D, Qi Y, Bachus K, Belis D, Cheng H, et al. Institutionalized governance processes: Comparing environmental problem solving in China and the United States. Glob Environ Chang. 2015; 31:163–173.
27. Hino M, Benami E, Brooks N. Machine learning for environmental monitoring. Nat Sustain. 2018; 1(10):583–588.
28. Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, et al. Changes in the global value of ecosystem services. Glob Environ Chang. 2014; 26:152–158.
29. Pascual U, Balvanera P, Díaz S, Pataki G, Roth E, Stenseke M, et al. Valuing nature's contributions to people: the IPBES approach. Curr Opin Environ Sustain. 2017;26–27:7–16.
30. Valdivia M, Galan JL, Laffarga J, Ramos J-L. A research and technology valuation model for decision analysis in the environmental and renewable energy sectors. Renew Sustain Energy Rev. 2020; 122:109726.
31. Ferraro PJ, Sanchirico JN, Smith MD. Causal inference in coupled human and natural systems. Proc Natl Acad Sci U S A. 2019; 116(12):5311–5318. https://doi.org/10.1073/pnas.1805563115 PMID: 30126992
32. Hinkel J, Cox ME, Schlüter M, Binder CR, Falk T. A diagnostic procedure for applying the social-ecological systems framework in diverse cases. Ecol Soc. 2015; 20(1).
33. Falk T, Vollan B, Kirk M. Tragedy of the commons. Essential Concepts of Global Environmental Governance. Routledge; 2020. p. 262–4.
34. Falk T, Spangenberg JH, Siegmund-Schultze M, Kobbe S, Feike T, Kuebler D, et al. Identifying governance challenges in ecosystem services management–Conceptual considerations and comparison of global forest cases. Ecosyst Serv. 2018; 32:193–203.
35. From Levi-Faur D. "big government" to "big governance". The Oxford handbook of governance. 2012. p. 3–18.

36. Ostrom E. Beyond markets and states: polycentric governance of complex economic systems. Am Econ Rev. 2010:641–672.
37. Mansbridge J. The role of the state in governing the commons. Environ Sci Policy. 2014; 36:8–10.
38. Brand U, Wissen M. The limits to capitalist nature: Theorizing and overcoming the imperial mode of living. Rowman & Littlefield; 2018.
39. Galaz V, Moberg F, Olsson E-K, Paglia E, Parker C. Institutional and Political Leadership Dimensions of Cascading Ecological Crises. Public Adm. 2011; 89(2):361–380.
40. Zhang Y. Governing the water commons in China: from historical oriental despotism to contemporary fragmented hydraulic state. Int J Water Resour Dev. 2018;1–19.