Tackling Wicked Problems With Transdisciplinary Participatory Approaches

Hans-Peter Plag

Mitigation and Adapatation Research Institute, Old Dominion University, Norfolk, Virginia, USA

Abstract Wicked problems are social or cultural planning problems that are difficult or impossible to solve. The syndrome of modern climate change and the rapid social developments pose many wicked problems to social planners aiming for adaption and sustainability. New leaders are required who are able to manage projects aiming to tackle these problems. A new education is needed to educate these leaders. The skill set required includes skills related to scientific understanding, technical skills, personal skills, and an understanding of the decision making in society and the relationship between science and society. Sustainability is an emergent property of a system. Consequently, learning sustainability is a lifelong processes, which an education of new leaders needs to account for. Sustainability science aims at finding pathways from the current system states and trends to a desired future expressed in societal goals. Sustainability science is challenged by the lack of an epistemology of how to validate pathways and interventions before they are implemented. Risk assessments of system trends and proposed interventions can help to govern the risk. Monitoring of the system trajectory is mandatory to ensure that any interventions is not pushing the system into an undesirable system state. Risk is a social construct, and risk perception is impacted by culture as well as personal and group cognitive biases. Considering the above, adaptation science indicates that tackling wicked problems requires besides a clear goal describing the desired future understanding of decision making in society, system knowledge including the fragilities of the systen and the hazards the system is exposed to, foresight and an understanding of the spectrum of possible future, and options and interventions to change the system trajectory. Considering that wicked and super wicked problems are unique, case studies are mandatory in order to tackle such problems. A transdisciplinary participatory case study template has been developed iteratively over a period of eight years and used in more than 150 case studies in the class room, in service-learning settings, internships and professional settings. The goal of each case study is to make recommendations for actionable interventions to a clearly identified stakeholder or group of stakeholders aiming to tackle a wicked problem.

1 Introduction

Modern society is challenged by a self-created multicrisis including modern climate change, biodiversity and wild life loss, pollution, inequality, and governance failures (e.g., Ceballos et al., 2015, 2017; Harte, 2018; Garnett, 2018; Scholes et al., 2018; Brondizio et al., 2019; Plag, 2020; Bradshaw et al., 2021). From local to global scales, the spectrum of possible futures increasingly is biased towards undesirable futures (e.g., Ceballos et al., 2015, 2017; Harte, 2018; Garnett, 2018; Scholes et al., 2018; Brondizio et al., 2019; Plag, 2020; Bradshaw et al., 2021; Brozovi¸, 2023). Considering this challenge, agreeing on desirable futures and finding pathways to such futures poses social planning problems that can be characterized as wicked or super wicked problems (Rittel & Webber, 1973; Levin et al., 2012).

Wicked problems are social or cultural problems that are difficult or impossible to solve because of incomplete or contradictory knowledge, the number of people and opinions involved, the large economic burden associated with progress towards a solution, and the interconnected nature of these problems with other problems (Rittel & Webber, 1973). Super wicked problems have four additional characteristics: (1) time is running out; (2) there is no central authority to address the problem; (3) those seeking to solve the problem are also causing it; (4) policies discount the future irrationally (Levin et al., 2012). Wicked and super-wicked problems can hardly be addressed in the framework of traditional discipline-based approaches, and a transdisciplinary approach is needed to tackle these problems.

Tackling wicked problems successfully requires a participatory transdisciplinary approach including imagination (Brown et al., 2010). Tackling wicked and super wicked problems inherently requires a learning process embedded in systems thinking. A new leadership is needed with skills enabling the facilitation of this learning process. Considering that wicked and super wicked problems are unique (see Section 3.1) case studies are crucial parts of any approach to tackling such problems. A *Case Study Template (CST)* has been developed that can be used in educational programs to educate and train new leaders in sustainability, and it can be integrated into different methodological approaches to tackling real-world wicked problems.

2 Learning Sustainability: The Need for a new Sustainability Leadership

Traditionally, sustainability has been defined with the three pillars of social, environmental, and economic. In a systems thinking framework, these pillars are tightly intertwined. In fact, sustainability is an emergent property of a system, and only by observing and understanding the system can sustainability be understood and unsustainable system trajectories be detected and corrected.

In the past, much attention has been given to sustainability education with the goal to develop sustainability literacy. Rather less attention focused on how people can learn about sustainability and how to become sustainable, especially from experience. Learning sustainability is a relatively new concern in the discussion of sustainability. Education is challenged with the fact that learning sustainability is a life-long process. Moreover, learning sustainability requires a holistic approach based on experience with the overall system.

An appropriate educational program for sustainability leadership needs to provide an environment in which the students can learn sustainability through experience. This learning environment deepens the passion for a sustainable planetary life-support system and the human and non-human communities embedded in — and depending on — this life-support system; it emphasizes ethical reasoning as an integral part of learning sustainability, and it establishes learning sustainability as a way of life, a second nature, and integral part of culture. The learning environment emphasizes the realization that continuous learning is a crucial component of sustainability. It also exemplifies that in a world where people, education, science, research, institutions, organizations, professional associations, industry, governments, etc. pay insufficient attention to learning sustainability, sustainability will not emerge and the life-support system will continue to deteriorate and more and more species will go extinct, potentially including Homo sapiens.

2.1 Sustainability Leadership Skills, Competencies and Literacies

Acknowledging that sustainability is an emergent property of complex socio-ecological systems, leadership aiming for sustainability to emerge requires a deep understanding of the systems and their environments, as well as the social and ecological agents in the system and the decision making of these agents. Sustainability leaders require a broad range of skills, competences and literacies.

The skill set required for sustainability leadership are summarized in Table 1. Developing these skills in educational programs requires these programs to address a wide range of topics including, but not limited to complexity, systems of systems, cognitive biases, deterministic versus probabilistic views of the future, risk assessment, dealing with uncertainty and ambiguity and seeing opportunities in ambiguity, knowledge creation in transdisciplinary partnerships, collaborative skills, team building, stakeholder engagement, tackling wicked problems, and including experiential element in tackling these problems.

Sustainability leadership is based on a variety of principles, and these principles need to be integrated in educational programs:

Table 1. Skills deemed relevant for sustainability leadership enabling the tackling of wicked problems.

Type of Skills	Specific Skills
Scientific understanding:	• system thinking • understanding uncertainties and probability • accepting limited predictability • insight into resilience, fragility, hazards • "think like an engineer but consider nature as part of the system"; "combing gray and green"; "more focus on adaptation than mitigation"
Technical skills:	• understanding the physical, chemical and biological processes and being able to translate them into models • combining the understanding with strong computational and numerical skills • handling of data, visualization, • understanding and using new approaches (crowd sourcing, big data, citizen scientists, ...) • web communication • data assimilation in models
Science and society:	• understanding decision making in society • having insight into human behavior • being able to communicate scientific evidence including uncertainties and probabilities • recognizing paradigms that are implicit in decision making and assessing their validity • after failure, having resilience to recover but also taking time to consider better options
Personal skills:	• being able to integrate into an interdisciplinary environment: not being an expert in all fields but being able to communicate with experts in other fields • reflective capabilities: understanding and accepting personal and community biases • adaptive capabilities: being able to modify plans and activities if circumstances change

- Think globally and toward the future: The current and future impacts need to be considered each decision made might have on other countries, society, oceans, animals, communities, waste, resources, etc.

- Understanding the interconnections of systems: It is vital to recognize how each group of related factors (people, objects, processes, etc.) are connected and impact each other.

- Protect nature and people: Decisions should be made that will reduce the negative impacts on 2nd and 3rd levels of people, processes, the environment, and economies.

- Lead by example in your actions: This requires integrity in personal responsibility in jobs, actions, and participation in organization. It also implies holding ones own organization accountable to lead by example in its actions, and holding oneself accountable.

- Transform business as usual: Leaders will change habits and initiate a different path in the span of their control.

There are five core capabilities that enable sustainability leadership:

- **Systems thinking**: Connected, holistic thinking. Understanding the context behind a problem and its relationship to trends in broader environments. For example, a sustainability leader grasps the system of relationships in which the system under consideration is embedded: Flows in and out, surrounding and interconnected systems, interactions between human and non-human systems. Requires multidisciplinary backgrounds combining technical and creative fields, as well as expertise and knowledge in principles of systems management such as resilience and managing for emergence.

- **External collaboration**: Work with entities beyond the own organization. Significant environmental impact may be found in collaboration. Collaboration helps organizations build social capital, explore new opportunities and shape the contexts in which they operate. Investing in partnerships between governmental organizations, NGOs and businesses.

- **Social innovation**: The magnitude of sustainability challenges demands a fundamental reengineering of societal processes. Leaders with social innovation competence view this challenge as a growth opportunity. Social innovators find ways to redesign processes that create social value. They question the status quo and treat constraints as transformable. Within organizations, innovative leaders encourage social entrepreneurship among employees and prioritize interdisciplinary teams.

- **Sustainability literacy**: Sustainability-literate leaders are aware of emergent environmental and social trends, and the risks and opportunities they create for society. Fundamentally, they understand the changing roles of sectors, organizations and groups in society. They see the need for conducting environmental and social cost accounting, or using tools for scenario planning, backcasting, and hot spot analyses.

- **Active values**: A leader with active values is mindful of emotions and motivations and sensitive to those of others. Mindful leaders can view themselves and their work as part of a larger purpose, motivating them to harness organizations to improve society.

Finally, sustainability leadership requires an understanding of the system challenges that can prevent sustainability to emerge and the capability to develop viable strategies meeting these challenges and maintaining the community embedded in the life-support system. This requires:

- Understanding the decision-making framework and knowing the stakeholders.

- Assessing a situation by reflecting on own biases that could impact the assessment; understanding the biases of others and of the community, and being aware of the limitations these biases constitute for possible paths of the system.

- Knowing the system, the members, the life-support system.

- Analyzing the fragilities of the system under consideration.

- Detecting and understanding threats and assessing risks.

- Developing foresight - and interacting with others about the desirable futures.

- Working with the community to develop options and interventions.

- Implementing intervention and critically - and continuously - assessing their impact on the community and its life-support system.

Being a leader in sustainability requires three important literacy. Educational programs for a new leadership need to have a focus on developing and extending these literacies:

- **Information Literacy**: "Information Literacy lies at the core of lifelong learning. It empowers people in all walks of life to seek, evaluate, use and create information effectively to achieve their personal, social, occupational and educational goals. It is a basic human right in a digital world and promotes social inclusion of all nations" Garner (2006). The fact that in modern society available and accessible information is rapidly growing and often changing while the quality of information is increasingly difficult to assess requires a high level of information literacy. Separating truth-based information from misinformation and disinformation is increasingly a major challenge in modern society. Understanding the complex ways in which information is today made available and how reliable sources can be discovered is an important skill not only for experts but also the general public. The transient nature of a growing fraction of the information available in the digital world also poses a challenge to the use of that information. A key aspect of information literacy is the capability to identify rapidly whether a given information source is of sufficient quality and reliability. Information literacy includes an awareness of how to engage with the digital world, how to find meaning in the information discovered, how to identify and articulate what kind of information is required, how to evaluate information for credibility and authority, how to use information ethically, and how to include information in professional communication.

- **Sustainability Literacy**: This includes the knowledge, mindset, and skills that allow individuals and communities to make informed decisions on actions that ensure a desirable and sustainable future. As emphasized above, developing sustainability literacy by learning sustainability is a life-long process. Having an understanding of this learning process is integral part of sustainability literacy. Likewise, understanding that sustainability is an emergent system property depending on many decision in the integrated system of humanity embedded in, and interacting with the *Earth's life-support system (ELSS)* is central to sustainability literacy. At the basis of sustainability literacy is the perception of flows in the planetary physiology and the feedback loops that impact these flows as the key to sustainability emerging.

- **Risk and Resilience Literacy**: This includes the ability to understand, evaluate, and make good decisions about risk (for a discussion of the risk concept, see Section 4.2). It also includes the insight that resilience is an emergent system property and that addressing the system fragilities provides an avenue to increasing the probability that resilience will emerge. Any human endeavor carries some risk, including interventions that aim at progress towards more sustainability through mitigation and adaptation. Some interventions come with higher risk than others, and the choices of how to address challenges need to be informed by risk considerations. The ability to perceive the risks individuals, communities and the ELSS are exposed to is essential for decision informed by the awareness of these risks. Understanding that risk and resilience perception is subjective and depends on individual and cultural conditions, as well as cognitive biases is part of risk and resilience literacy (see Figure 5).

2.2 The Importance of Flows for Sustainability

For both, human and non-human communities, sustainability emerges as a result of flows between the ELSS and the embedded communities. In fact, for humanity, sustainability requires:

- to consume nature's flows while conserving the stocks (that is, live off the 'interest' while conserving natural capital).

- to increase society's stocks (human resources, civil institutions) and limit the flow of materials and energy (Brown et al., 2005).

Human communities are embedded in the planetary life-support system and linked to the ELSS through flows of materials and energy (Fig. 1). For humanity as a whole, sustainability can only emerge if these flows do not degrade and deplete the ELSS. Unlike for other animals, for human communities

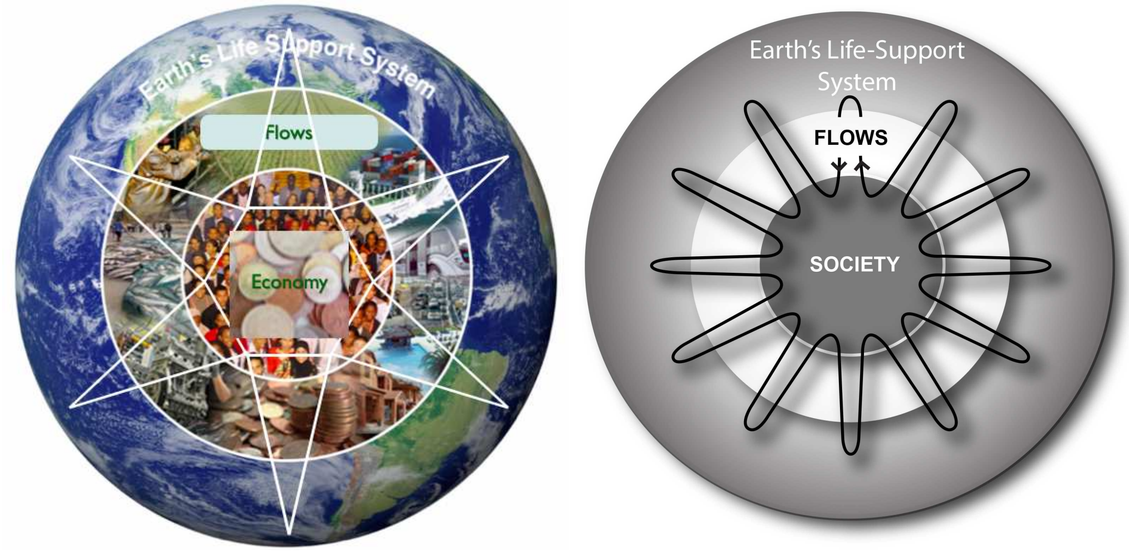


Figure 1. Humanity in the planetary life-support system. Similar to all animal communities, human communities are embedded in, and interact with, the planetary life-support system. Left: All human communities depend on flows from the ELSS into the communities and flows back into the ELSS impact the ELSS. Almost all interactions with the ELSS in modern take place within a game-like economic system overlaid on the real world. Modified from Plag & Jules-Plag (2017). Right: Sustainability of a community emerges among others as a result of the flows of material and energy between the community and the ELSS. From Plag (2020).

these flows are regulated by ethics, social norms, and – more recently – economic rules (Plag & Jules-Plag, 2017). This emphasizes the central role of ethics and social norms for sustainability. Since a few hundred years, economic rules have an ever increasing weight in the determination of flows between humanity and the ELSS as well as within humanity. In fact, in modern times, economy provides the link between the ELSS and the human communities embedded in the ELSS (Fig. 1). Education for sustainability leadership has to be centered on understanding the importance of flows both for sustainability and conservation. The role that ethics, social norms and the mainstream economic model play for the regulation of these flows both between ELSS and humanity and within humanity need to be emphasized in all assignments and research conducted by the students in such educational programs. In fact, the *de facto*purpose of economy has to be understood and respected in order for sustainability to emerge in the intertwinded social, ecological, and economic systems.

Considering this, the mainstream economic model increasingly determines whether sustainability can emerge or not. Based on the notion that "*the purpose of a system is what it does*" (POSIWID, Beer, 1985), we can ask the question "What is the purpose of economy?" Reflecting on the flows between the ELSS and any community of human or non-human animals (Fig. 2), it is clear that the *de facto*purpose of economy is to meet the needs of humans while safeguarding the ELSS, on which the welfare of all human and non-human communities depends. This *de facto*purpose is very well captured in the definition of sustainable development given by Griggs et al. (2013): "¡i¿A sustainable development is one that meets the needs of the present while safeguarding the Earth's life-support system, on which the welfare of all future generations depends¡/i¿."

However, the "official" purpose of modern economy introduced by Smith (1776), i.e., the creation of human wealth, is not in agreement with the *de facto*purpose, and a divergence of *de facto*and official purpose often lead rapidly to unsustainability. The subsequent push to grow the economy and human wealth through increasing consumption (e.g., Keynes, 1936; Lebow, 1955) resulted in ever growing flows between the ELSS and the socioeconomic system and back into the ELSS – the opposite of what is required for sustainability. The current mainstream economic model is still growth-focused and in fact growth-dependent, and it requires ever increasing flows. Thus, this model is in direct conflict with the

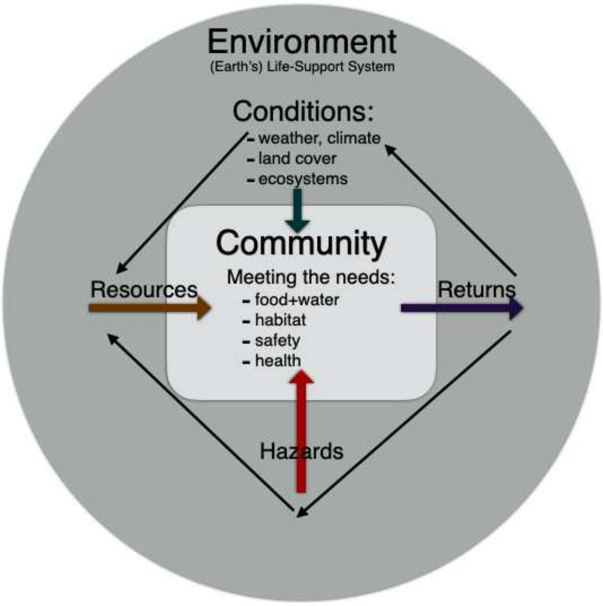


Figure 2. All communities of human and non-human animals embedded in the ELSS have basics needs that are met by taking resources from the ELSS. They require appropriate environmental conditions, and they are exposed to hazards. They also return waste and residual resources back into the ELSS. A sustainable supply system meeting the community's needs will have to ensure that the resources taken and the wastes returned are not degrading the ELSS. In recent centuries, humans have overexploited the ELSS and overloaded the ELSS with waste. The resulting changes in the ELSS are now changing the environmental conditions, amplifing hazards, and reducing available resources.

requirements for sustainability to emerge.

In order for sustainability to emerge, the principle of sustainable development as defined by Griggs et al. (2013) needs to be accounted for in all case studies on sustainability and conservation. However, this principle can only be adhered to if the official purpose of economy is better aligned to the *de facto*purpose. A workable purpose of economy would be: "¡i¿¡b¿To equitably meet the needs of the presence while safeguarding the Earth's life-support system, on which the welfare of all current and future life on Earth depends¡/b¿¡/i¿." It is obvious that only a fundamental transformation could bring the current growth and wealth-focussed economy to an economy with this official purpose. This implies that in the spectrum of possible futures only those tranformation futures that emerge from such an economy have a realistic chance to avoid a collapse future.

3 Wicked Problems in Sustainability and Conservation

Most sustainability and conservation-related social planning problems are wicked problems (Fig. 3). Wicked problems are social or cultural problems that are difficult or impossible to solve because of incomplete or contradictory knowledge, disagreement about the problem definition, the number of people and opinions involved, the large economic burden associated with progress towards a solution, and the interconnected nature of these problems with other problems (Rittel & Webber, 1973). In short, a wicked problem has innumerable causes, is tough to describe, and does not have a right answer. Addressing environmental degradation including biodiversity loss, climate change, and pollution, terrorism, and poverty are classical examples of wicked problems. Some of them actually classify as super wicked problems as defined by Levin et al. (2012). Wicked and super wicked problems are the opposite of complex but tame or benign problems, which can be solved in a finite time period by applying standard techniques. Not only do conventional processes fail to tackle wicked problems, they also may exacerbate situations by generating undesirable consequences.

3.1 Wicked and Super Wicked Problems

As mentioned above, wicked problems are social planning problems aiming at tackling social problems and finding pathways to desirable futures. Understanding the characteristics of these problems is crucial for tackling these problems. Therefore, the characteristics are summarized here.

Rittel & Webber (1973) give ten characteristics that turn a problem into a wicked problem:

- There is no definitive formulation of a wicked problem. It's not possible to write a well defined statement of the problem, as can be done with an ordinary problem.
- Wicked problems have no stopping rule. You can tell when you've reached a solution with an ordinary problem. With a wicked problem, the search for solutions never stops.
- Solutions to wicked problems are not true or false, but good or bad. Ordinary problems have solutions that can be objectively evaluated as right or wrong. Choosing a solution to a wicked problem is largely a matter of judgment.
- There is no immediate and no ultimate test of a solution to a wicked problem. It's possible to determine right away if a solution to an ordinary problem is working. But solutions to wicked problems generate unexpected consequences over time, making it difficult to measure their effectiveness.
- Every solution to a wicked problem is a "one-shot" operation; because there is no opportunity to learn by trial and error, every attempt counts significantly. Solutions to ordinary problems can be easily tried and abandoned. With wicked problems, every implemented solution has consequences that cannot be undone.
- Wicked problems do not have an exhaustively describable set of potential solutions, nor is there a well described set of permissible operations that may be incorporated into the plan. Ordinary problems come with a limited set of potential solutions, by contrast.
- Every wicked problem is essentially unique. An ordinary problem belongs to a class of similar problems that are all solved in the same way. A wicked problem is substantially without precedent; experience does not help you address it.
- Every wicked problem can be considered to be a symptom of another problem. While an ordinary problem is self-contained, a wicked problem is entwined with other problems. However, those problems don't have one root cause.
- The existence of a discrepancy representing a wicked problem can be explained in numerous ways. A wicked problem involves many stakeholders, who all will have different ideas about what the problem really is and what its causes are.
- The planner has no right to be wrong. Problem solvers dealing with a wicked issue are held liable for the consequences of any actions they take, because those actions will have such a large impact and are hard to justify.

Conklin (2006) generalized wicked problems with six defining characteristics:

- "You don't understand the problem until you have developed a solution. Indeed, there is no definitive statement of "The Problem." The problem is ill-structured, an evolving set of interlocking issues and constraints.
- Wicked problems have no stopping rule. Since there is no definitive "The Problem", there is also no definitive "The Solution." The problem solving process ends when the solution is acceptable or when you run out of resources.
- Solutions to wicked problems are not right or wrong, simply "better," "worse," "good enough," or "not good enough."
- Every wicked problem is essentially unique and novel. There are so many factors and conditions, all embedded in a dynamic social context, that no two wicked problems are alike, and the solutions to them will always be custom designed and fitted.

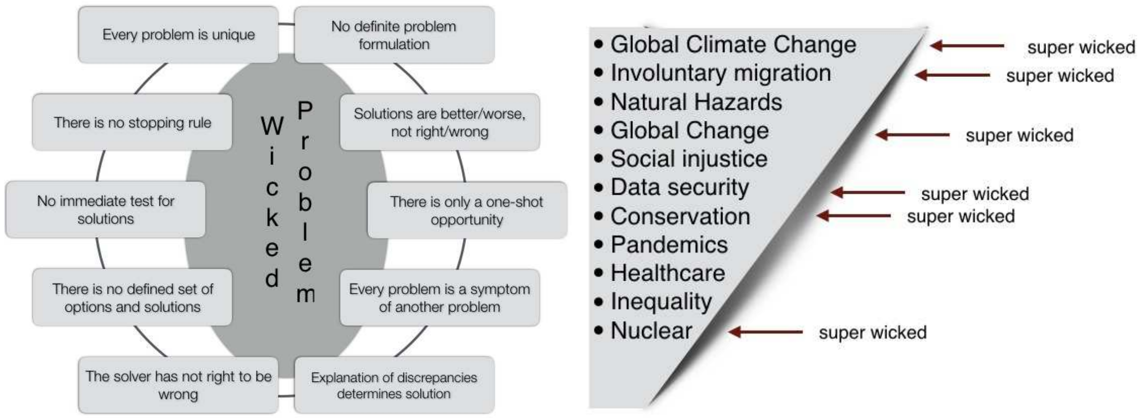


Figure 3. Left: Ten criteria that characterize wicked problems. The criteria are taken from Rittel & Webber (1973). Right: Examples of wicked and super wicked problems. The wicked problems are in the social planning problems of finding pathways to desirable futures under the indicated challenges.

- Every solution to a wicked problem is a "one-shot operation," every attempt has consequences. As Rittel says, "One cannot build a freeway to see how it works." This is the "Catch 22" about wicked problems: you can't learn about the problem without trying solutions, but every solution you try is expensive and has lasting unintended consequences which are likely to spawn new wicked problems.

- Wicked problems have no given alternative solutions. There may be no solutions, or there may be a host of potential solutions that are devised, and another host that are never even thought of."

Super wicked problems have four additional characteristics: (1) time is running out; (2) there is no central authority to address the problem; (3) those seeking to solve the problem are also causing it; (4) policies discount the future irrationally (Levin et al., 2012). While the characteristics that define a wicked problem relate to the problem, the additional ones that define a super-wicked problem relate to the agent trying to solve it. Examples of super-wicked problems are shown in Fig. 3.

There is an additional characteristics of super wicked problems that is often overlooked. The inherent value of the non-human environment is in general either negelected or not appropriately considered. There are recently many efforts to value ecosystem services and integrate these values into economic assessments in the evaluation of potential interventions for tackling wicked or super wicked problems. However, these ecosystem services are valued based on an anthropocentric viewpoint and any inherent value of nature is not considered.

3.2 Strategies for Tackling Wicked Problems

Wicked and super-wicked problems can hardly be addressed in the framework of traditional discipline-based approaches, and a transdisciplinary approach is needed to tackle these problems (Brown et al., 2005; Australian Government, 2007). Importantly, the emerging fields of adaptation science (Moss et al., 2013) and sustainability science (Kates et al., 2001; Clark & Dickson, 2002; Miller et al., 2014) are therefore inherently transdisciplinary.

For tackling these problems, there are basically three main different strategies (Roberts, 2000, and Fig. 4):

- Authoritative: Vesting the responsibility for solving the problems in the hands of a few people. While this results in a reduction in the number of stakeholders and reduces problem complexity, authorities and experts may not have all the perspectives needed to tackle the problem.

- Competitive: Pitting opposing points of view against each other. While different solutions can be weighed up against each other and the best one can be chosen, this creates a confrontational

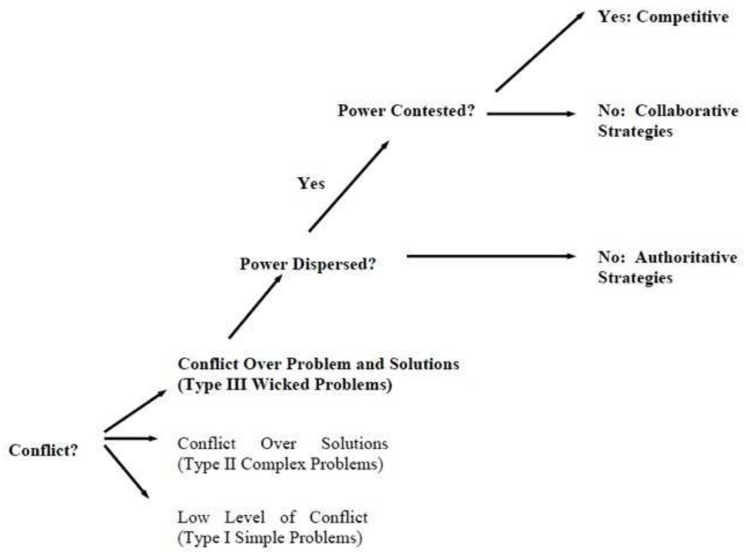


Figure 4. Strategies for tackling wicked problems. From Roberts (2000).

environment in which knowledge sharing is discouraged, and parties involved may not have an incentive to come up with their best possible solution.

- Collaborative: Engaging all stakeholders in order to find the best possible solution for all stakeholders. Involves meetings in which issues and ideas are discussed and shared understanding is developed. The advantage is that a common, agreed approach is formulated, and the chosen solution has a good chance of being supported by most stakeholders.

In learning sustainability, emphasis has to be on a collaborative and participatory approach that involves all stakeholders in the process of learning from experience. Compared to authoritative and competitive approaches, which both have the disadvantage of excluding many stakeholders from tackling the problem, collaborative approaches aim to ensure that all, or at least, most points of view are considered (Mauser et al., 2013). Participatory modeling is one of these collaborative approaches (e.g., Guyot & Honiden, 2006; Le Page et al., 2011; A. et al., 2016; Henly-Shepard et al., 2015; Garcia et al., 2020).

In a first step, participatory modeling aims at a shared understanding of the wicked problem. Shared understanding is not the same as consensus. It does not mean everybody agrees with each other. Shared understanding among stakeholders in a project means that the stakeholders know about each others' concerns and goals. Reaching a shared understanding often results into a goal statement that describes the wicked problem at a very high level. Mapping the initial dialog is important to overcome fragmentation and reach a join understand (Conklin, 2006). Having a joint understanding does not mean the same as reaching a consensus. It means that the different views of the problem and the different interests of the stakeholder are known to all and there is understanding of where these differences originate and what they mean for tackling the problem.

The process of reaching a shared understanding is impacted by the mental models each agent has developed over time (e.g., Biggs et al., 2011). These mental models are the result of the individual experiences and, at the same time, determine what an individual experiences in a specific situation (Koch, 2019). Thus, the perceived image of a situation can differ significantly from the *de facto*real world situation (Fig. 5). Raising the awareness of these differences between the *de facto*real-world and the perceived world represented in mental models (Mercier & Sperber, 2017) is a prerequisite for successful participatory efforts towards sustainability and conservation.

In a next step, the modeling aims at understanding the system underlying the wicked problem. The goal is to develop a conceptual model that could help to explore scenarios towards a common goal of a group or community.

While wicked problems related to the same issue often are grossly similar, they are discretely different, which necessitates each problem to be addressed individually. Solutions cannot be generalized. Poverty in, e.g., California is grossly similar but discretely different from poverty, e.g., in Angola, and there is no practical set of characteristics that defines poverty. When tackling poverty in these two locations, the stakeholders involved, the societal framework, and the available interventions all are very different.

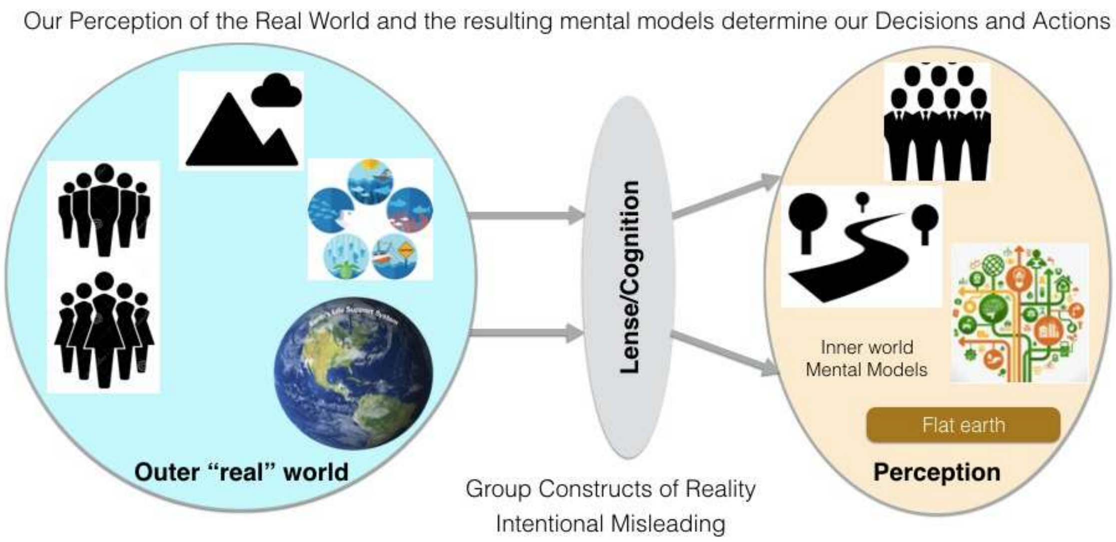


Figure 5. The *de facto*real world and mental models resulting from experience and cognitive biases.

This uniqueness of wicked problems seems to require that case studies focusing on a location and a wicked problem provide a reasonable setting for the learning experience related to sustainability and conservation. Educational sustainability and Conservation Leadership programs therefor should be built around case studies of real-world problems. These case studies provide for an experiential learning setting Beard & Wilson (2018). Optimally, the students are exposed to learning by experience in a triple loop with three sequential case studies with increasing levels of real-world experience (Hill et al., 2020).

4 Transdisciplinary Case Studies in Sustainability and Conservation

As pointed out in the previous section, tackling wicked problems requires a participatory transdisciplinary approach including imagination (Brown et al., 2010). The uniqueness of each wicked problem favors case studies as a principal approach to wicked problems. Therefore, a template for transdisciplinary case studies in sustainability and conservation was developed and heavily utilized in the development of the learning environment for students, as well as othercase studies of wicked problems. The CST is designed for tackling wicked problems related to sustainability, mitigation of threats, and adaptation to changes.

For wicked problems is true what in general applies to any Gestalt: The whole is bigger than the sum of its parts (e.g., Jackson, 2008). Therefore, no matter how many disciplines and teaching modes are being integrated, there will always be "unknown" parts and emergent properties, which is a good thing. Trouble arises from an attempt to fit the whole into the sum of its parts. The CST therefore does not attempt to break down a wicked problem into parts or approach the problem with a combination of disciplines. The CST respects the integrity and wholeness of the problem and tackles it by perceiving its Gestalt through careful system mapping with a systems thinking mindset.

4.1 Background

The CST is based on sustainability science and utilizes the core concepts of adaptation science. As pointed out above, sustainability is an emergent property of a complex system. Two criteria need to guide human behavior in order to maintain the health of the planetary life-support system and for sustainability to emerge: (1) humans need to consume flows in this life-support system while conserving the stocks (that is, live off the interest while conserving natural capital), and (2) increase society's stocks (i.e., human resources, civil institutions) and limit the flow of material and energy as much as possible (Brown

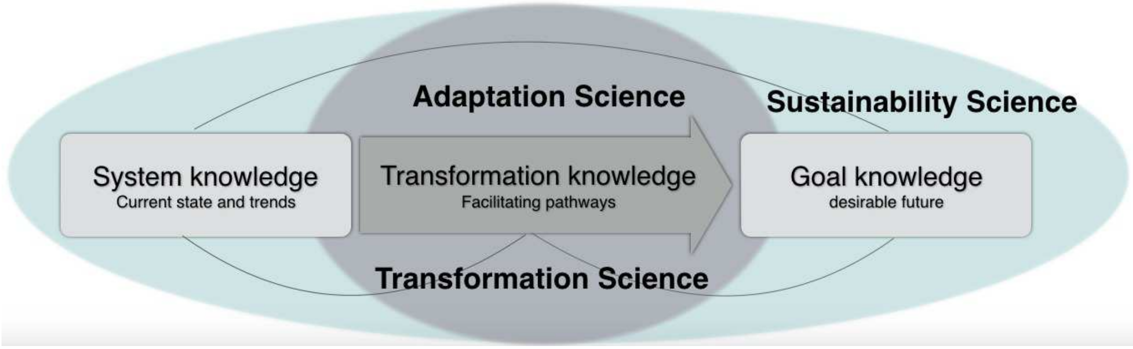


Figure 6. The three main parts of sustainability science. Sustainability science relies on three main kinds of knowledge: system knowledge, goal knowledge, and transformation knowledge. While the epistemology of creating system and goal knowledge is well developed, the epistemology of creating transformation knowledge is in its beginning. From Plag & Jules-Plag (2019).

et al., 2005). Both are central aspects of a regenerative culture.

A particular challenge to the quest for sustainability arises from the need to create transformation knowledge guiding the development of interventions to make progress towards sustainability as the emergent property of the integral system that represents human communities embedded in their environment. Science needs to support society and interact with societal agents in efforts to create this transformation knowledge. Reaching societal goals such as the *Sustainable Development Goals (SDGs)* of the United Nations presents policy makers with a complexity individually and through many interconnections (Utting, 2013; Plag & Jules-Plag, 2017; Plag et al., 2017; Plag & Jules-Plag, 2019; Soergel et al., 2024). At the same time, the unsustainability of the current global trajectories of society and the ELSS introduces an unparalleled urgency to develop the necessary transformation knowledge. A major gap exists in the absence of an epistemology for the creation of transformation knowledge. While there are increasingly efforts to carry out transformation research in "real-world laboratories," there is no thorough epistemological approach available for this new type of research.

Because of its transformational and transdisciplinary character, sustainability science differs from traditional modes of knowledge production. Sustainability science links system knowledge and goal knowledge through transformation knowledge (Fig. 6). System knowledge informs about what might happen, identifies and assesses the system fragilities and the possible threats and hazards, and explores the past, current and potential future system trajectories. Natural sciences have focused on system knowledge and created a broad basis of that knowledge. Goal knowledge describes what we want to happen and what desirable futures we want to realize. Transformation knowledge identifies the interventions required to change the system trajectory and to facilitate pathways to desirable futures Wiek et al. (2012). Over the last few decades, social sciences have developed both the epistemology and methodology for the creation of goal knowledge (Miller, 2013). The elaborate process that led to the agreement on the seventeen SDGs exemplifies the level of goal knowledge that can be reached today (United Nations, 2015), and a transition to global governance by goal-setting appears feasible. What is currently lacking is a fully developed transformation science that links the system and goal knowledge through the disturbances and interventions needed to ensure a progress towards desirable futures (Miller et al., 2014; Grunwald, 2015). Transformation science as part of sustainability science focuses on the identification of disturbances and interventions that can divert the ELSS from its current trajectory out of the "safe operating space for humanity" (Rockström et al., 2009; Steffen et al., 2018) onto a trajectory towards desirable futures closer to the agreed-upon goals expressed in the SDGs.

However, the epistemological basis for the creation of transformation knowledge has been neglected to a large extent (Wiek et al., 2012; Miller et al., 2014; Grunwald, 2015). A major unsolved problem in the epistemology of sustainability science is therefore the understanding of how transformation knowledge can be generated, tested, and validated. This raises important epistemological questions: How

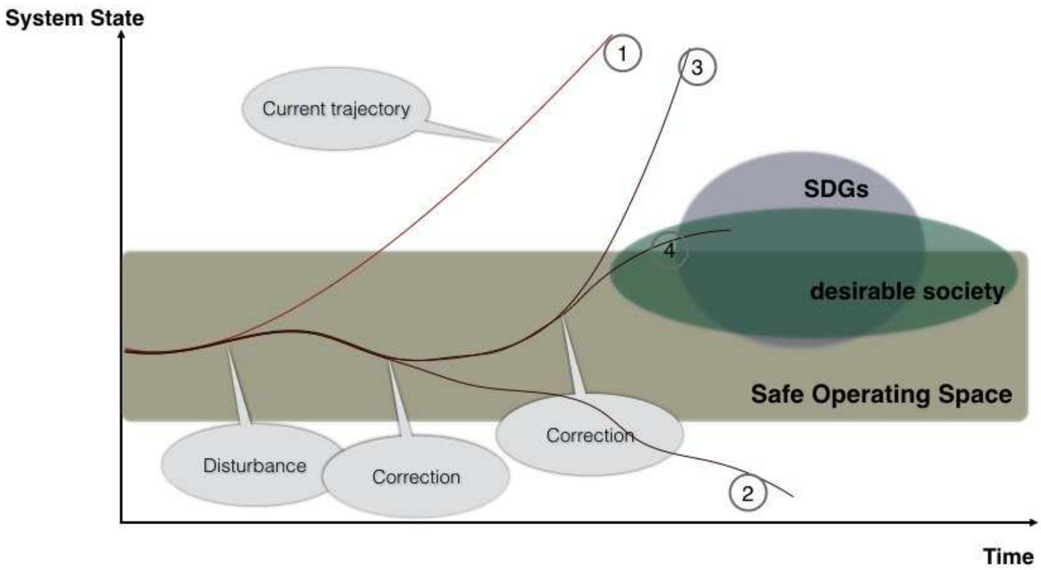


Figure 7. The iterative nature of bending system trajectories towards desirable futures. Achieving the transformation from the current state and trend to a desired future requires an iterative process of disturbances exceeding the system's resilience and corrections to bring the system's trajectory closer to the desired future. From Plag & Jules-Plag (2019).

is knowledge for transformation produced? What is the role of experimental interventions in producing transformation knowledge? What theories can support knowledge production for transformational sustainability?

Developing the interventions to change the system trajectory in a desirable way is an iterative process (Fig. 8). Any intervention through policies, organizational changes, and technologies needs to be validated as far as possible prior to implementation, which poses epistemic challenges due to the fact that a priori validation is impossible: only during implementation can the impacts be monitored and there is no chance to go back in time and try another intervention. Model simulations can be used to explore possible futures under different scenarios for drivers, an approach used, e.g., for the Millennium Ecosystem Assessment (e.g., Carpenter et al., 2005) or the assessment of future climate change (e.g., IPCC, 2018).

The iterative nature of implementing transformation (7) requires detailed monitoring of the trajectory of the complex system after interventions in order to ensure that the resulting trajectory brings the system closer to the desired future and accepted goals and to detect in a timely manner the need for further interventions.

The CST accounts for the challenges of sustainability science and aims to integrate system knowledge with the creation of goal knowledge and the development of the transformation knowledge that links the present with the desired future. In doing so, the CST has a living systems thinking perspective of the world. The very common event-oriented perspective focuses on symptoms and aims to reduce the direct causes for these symptoms. By doing so, the problem-solving remains at a superficial level that links apparent causes to symptoms without understanding the fundamental casual loops that can only be captured in a systems thinking perspective. The CST guides the investigations from the common superficial level into the fundamental level where root causes can be discovered and addressed.

4.2 Foresight, Risks, and Resilience in Times of Rapid Changes

A central focus in the cases studies aiming at tackling wicked problems is on the development of foresight and the assessment of risks associated with possible futures and interventions intended to put the system on a trajectory towards a desirable future. During times when changes are very slow and no big surprises are likely, foresight can be based on understanding the past. Over many centuries, civilizations developed foresight utilizing the knowledge of the past for extrapolations and assessments of the possible futures.

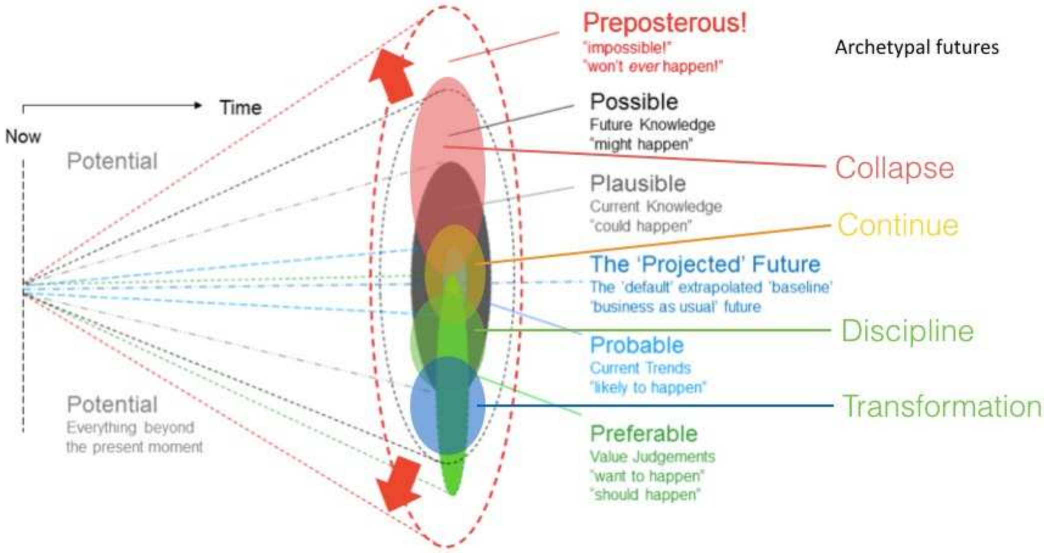


Figure 8. The spectrum of possible futures. The spectrum of possible futures includes a wide range of futures from those possible, plausible, projected, probable, and preferable, but not all of them are overlapping. Importantly, there are four archetypal futures, i.e., continue, discipline, transformation, and collapse (Bengston, 2018).

However, in times of rapid and even accelerating changes, this approach is bound to fail. At the same time, when rapid changes are likely, foresight is fundamental for survival. Cognitive biases impact foresight and often lead to the exclusion of a range of possible futures from considerations (Neugarten, 2016). The need for foresight in terms of environmental, social, technological and economic futures has increased in recent decades as the pace of change has accelerated and surprise emerge at an increasing frequency. Successful conservation and sustainability leadership dealing with the impacts of increasingly more rapid change on social-ecological systems depends on the ability to anticipate the futures that may emerge. Unfortunately, most traditional scientific tools are designed to study gradual changes and are not well suited for studying a future that may emerge from rapid changes or the crossing of tipping points and thresholds. Futures research is a transdisciplinary field of inquiry that has been developing for more than 50 years (Bengston et al., 2012). It offers a set of approaches that can be used to explore the spectrum of possible futures in a setting of rapid and often unpredictable changes. Among the futures research methods are several forms of scenario analyses, and these have been applied in a number of environmental and societal risk assessments (e.g., Carpenter et al., 2005; IPCC, 2018). Scenario-based methods are also used for the development of foresight in the case studies (Ducot & Lubben, 1980). But in futures research, a range of other useful methods for exploring possible, plausible, and preferable futures has been developed, and insights into the nature of change has been broadened (e.g., Robinson, 1988).

Importantly, perspectives for thinking creatively and deeply about the future have been developed as part of futures research (Bengston, 2018). These development are increasingly integrated into the learning environment of the Sustainability and Conservation Leadership program at ODU and the case studies carried out by the students. In particular, the students are introduced to the concept of a spectrum of possible futures (Fig. 8), and they are confronted with the fact that the spectrum of possible futures includes four basic archetypal types of futures: Continue, Discipline, Transformation, and Collapse (Bengston, 2018). It is expected that the inclusion of futures research in the program will further improve the development of strategies for tackling the wicked problems considered with increased adaptive capacity and by more effectively accounting for surprises.

Once a desirable future has been agreed upon among the relevant stakeholders, backcasting can be used to develop interventions that can be implemented in the now to reach the desired future (Robinson, 1990; Dreborg, 1996; Holmberg & Robèrt, 2000). The design of strategies and policies can also benefit

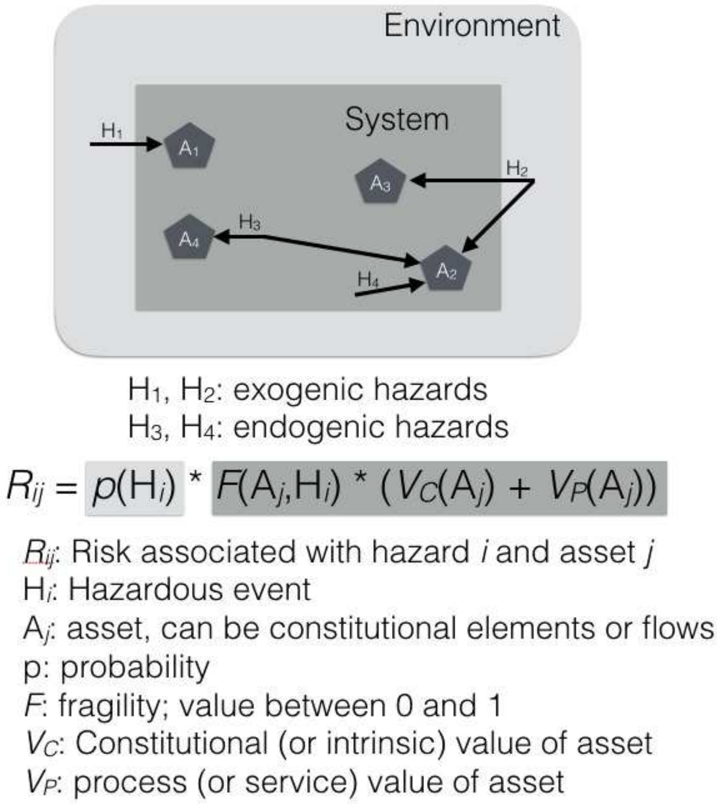


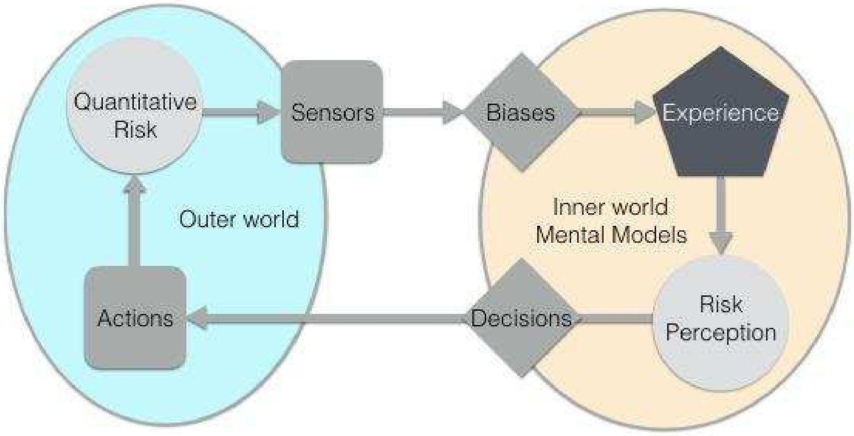
Figure 9. Risk as a function of hazard probability, fragilities and assets.

from starting at the desired outcome and utilizing backward design (Wiggins & McTighe, 2005).

Interventions designed to put the system on a trajectory toward a desirable futures always come with a risk, and risk assessments provide crucial input for the decision making on which interventions to recommend. Particularly in times of rapid changes, assessing risk is a challenging task. Risk can be defined as the product of probability (of the hazardous event) and the consequence (Fig. 9). The consequence is often measured in currency and is the product of the fragility of an asset exposed to the hazard and the value of the asset.

Importantly, similar to perception of the *de facto*world (see Fig. 5), risk perception often differs from the *de facto*real-world risk. As a result, risk governance often overlooks high risks and amplifies minor risks. High risks arise often from extreme but low probability events, and there is a strong tendency to put these risks into the far future (Baum, 2015). Risks associated with events that have not been experienced before, including the full spectrum of Anthropocene Risks (Keys et al., 2019) are very often underestimated (Avin et al., 2018; Kuhlemann, 2019), leaving humanity exposed to global catastrophic risks (Tonn & Stiefel, 2014). Since resilience and sustainability are emergent properties of any system, these misjudgments can easily lead to negative consequences. In the case study, a focus is on reducing the differences between perceived risks and the *de facto*risks.

In risk assessments, it is important to consider both the constitutional or intrinsic value of the asset as well as its process or service value. For example, bees have an intrinsic value that can be lost in an hazardous event, and they provide an ecosystem service of value to both the ecosystem and humans that benefit from this service. While the constitutional value of a human product (e.g., a building or a truck) can be easily determined, assigning intrinsic values to elements in ecosystem poses a more difficult challenge and involves considerable ethical considerations (Vucetich et al., 2015). However, for a comprehensive risk assessment both the constitutional and process value of an asset need to be considered. For ecosystems and species in the ecosystem, determining the constitutional or intrinsic value is challenging, though. In the context of case studies, particular attention needs to be on the role of values and ethics and other extra-scientific factors, the handling of uncertainties and incomplete information, as well as the efficacy of quantitative versus qualitative analysis, which all are aspects still under debate (Hatfield & Hipel, 2002). Understanding how deep-seated values and cognitive biases impact risk perception and risk assessment is fundamental for meaningful risk assessments.



a

Figure 10. Risk and Perception. Risk perception is impacted by cognitive biases and can differ significantly from the *de facto*risk in the real world. Risk perception and mental models impact decision making and the design of interventions as part of risk governance.

In the past, we have distinguished between system vulnerabilities and hazardous events. However, the term "vulnerable" has different meanings and often is understood as being exposed to a potential hazard. For the analysis of the system capability to display resilience it is helpful to use the term "fragile," which only refers to the constitution of a system and the system processes without implying exposure to a danger that could exploit the fragility.

Most risks results from the interaction of a system with its environment (Fig. 9). We denote these risks as exogenic risks. Most hazards originate in the environment, and they trigger processes inside a system that can amplify or mitigate the impacts of the hazard.

There are also risks that are internal to a system. These endogenic risks are associated with failures of internal processes. Most of these risks are associated with positive feedback loops that can lead to run-away situations. In a systems thinking approach, understanding the fragilities of system stocks and flows provides a basis for a thorough risk assessment.

In most case studies, the goal to be achieved (i.e., the desirable future), includes some level of resilience and sustainability. It has become more clear recently that resilience literacy and sustainability literacy require more than resilience education and sustainability education, respectively. What is needed is "learning resilience" and "learning sustainability" and these are lifelong and often iterative processes.

Both, resilience and sustainability are emergent properties of a system. As such, there are no metrics to measure resilience and sustainability, which means they can only be assessed after the fact. With respect to resilience, a comprehensive risk assessment can inform us whether a community, ecosystem, social network, built environment, country, or humanity has a high probability of being resilient. Any disturbance of the system will provide more information on the emergent level of resilience of the system and we can learn from that and make adjustments: a never ending process of being "antifragile" (Taleb, 2012).

Importantly, system properties that render a system unable to display resilience or sustainability can be identified and classified. In general, the absence of resilience results from a hazardous event or trend exploiting system fragilities. Thus, identifying the constitutional and procedural fragilities of a system and removing or reducing these fragilities will enhance the chance that the system displays resilience. The risk assessment discussed above can inform these considerations.

The absence of sustainability results mainly from trends that push the system into a hazardous state or cause positive feedback loops. Identifying the trends that exclude sustainability can be a complex challenge since we need to assess the trends and use futures research and foresight to see whether these trends point towards a desirable future or a potential collapse. While we progress towards more desirable futures we need to continuously assess the projected trajectory and this is what "learning sustainability" is about.

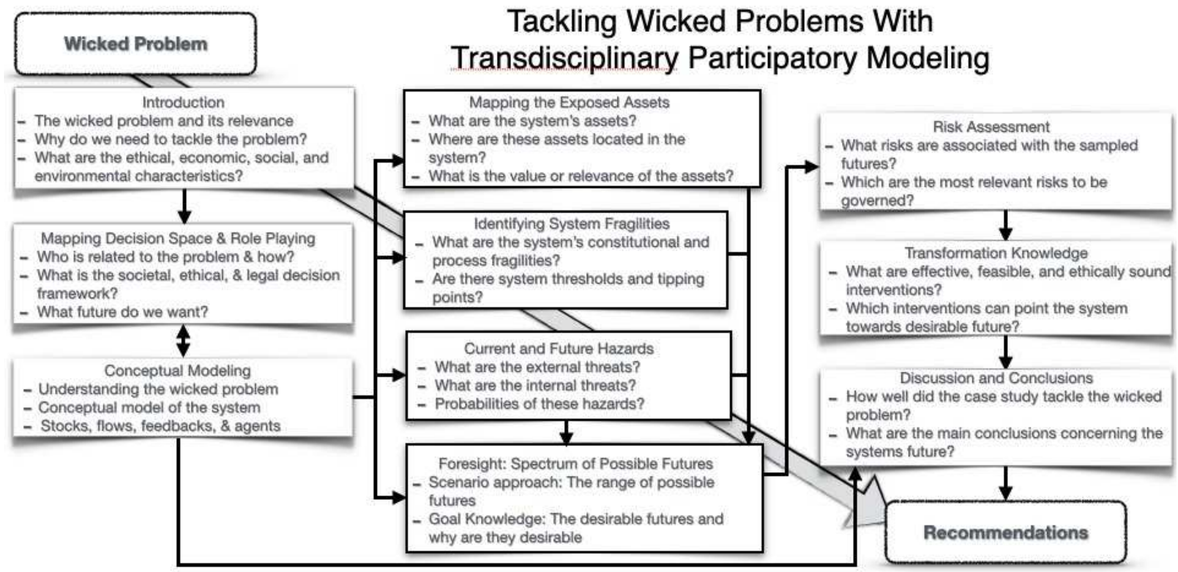


Figure 11. Case Study Template. The aim of a case study utilizing the CST is to address a wicked problem and to provide recommendations to selected social agents for transformative mitigation or adaptation actions that would help to tackle this wicked problem. The main outcome of a case study is the case study report. The version show in the diagram is Version 4.3.

4.3 Objectives of the Case Study

The goal of a case study is to tackle a wicked problem by developing options that would address the problem in the context of mitigation and adaptation science (Fig. 11). The CST ensures that the five main areas of adaptation science as defined in Moss et al. (2013) (i.e., the fragilities of the system, the hazards, foresight, decision making, and options) are reflected in the structure of the case study report, and that the case study takes a systems thinking approach.

The CST can be used for case studies carried out by individuals or groups. A case study can be combined with a virtual (simulated) or actual participatory modeling effort. In some cases, participatory modeling utilizing role playing can substitute for one that engages the societal agents of the wicked problem considered.

4.4 Case Study Outcomes and Readership

In all cases, the cases study outcomes consist of a detailed case study report and a presentation of the main aspects of the cases study. In more advance case studies, the participants are also asked to prepare promotional one-page summaries as well as a reflective video giving an overview of the case study. Additionally, all participants are requested to provide personal reflections on the learning experience of doing the case study.

The participants in a case study are asked to assume that they are writing the case study report in support of decision making by a specific stakeholder group engaged in tackling a real-world wicked problem. This implies that the case study paper is written in a way that a non-expert can understand the text. The recommendations are addressed to a well defined stakeholder group engaged in tackling the wicked problem.

4.5 Case Study Report

The case study report has nine sections corresponding to the nine boxes in Fig. 11. In addition, case study report should include an Executive Summary with sufficient information for executives to understand the challenge and the wicked problem, be able to extract actionable information from the recommendations, and to get sufficient justification for these recommendations.

The sections present the following information, with appropriate attention to detail and the appropriate bibliography:

- **Introduction**: The introduction gives a brief overview of the real-world issue being addressed. It gives a general description of the issue considered and why this issue constitutes a wicked or super wicked problem. Questions considered here include: What is the challenge? Where is this a problem? What system is being considering (eco-system, species, human community, ...)? Who (human or nonhuman) is impacted? What and who has caused the problem? Who is trying to solve/address the problem? Is this a wicked or super wicked problem? What has been done to address it? Who are the societal agents that may benefit from the case study report?

- **Mapping the decision space**: This section provides an analysis of the societal context and the decision space, including a mapping of stakeholders and a summary of relevant regulations, rules and norms. Who are the societal agents involved and impacted by the problem and how do they make decisions related to interventions? The relevant system is embedded in a societal framework with many stakeholders with potentially conflicting interests. The feasibility of any option proposed to move the system toward a desirable or desired future will depend on the decision making of these social agents, in particular those that have the authority to implement interventions impacting the future of the system. In most cases, this section includes a diagram that shows the considered stakeholders mapped over their interest in the problem and their authority and means to implement interventions. A table of the most relevant stakeholders detailing their interests and authorities should come with this stakeholder map. In many cases, this section discusses role playing exercises with the most relevant stakeholder groups or efforts in actual participatory modeling. A first result of this participatory effort is a goal statement agreeable by all relevant stakeholders.

- **Conceptual modeling**: This section aims at tackling the wicked problem through a participatory approach. It summarizes the participatory efforts and gives a detailed description of the real-world problem from a living systems thinking perspective. Based on the goal statement, a conceptual model representing this problem can be designed to deliver answers to the core questions. This conceptual model identifies the relevant stocks and flows and indicates the feedback loops. It also links the integrated environmental human and nonhuman system with the decision space relevant to implement transformative interventions. A graphical presentation of the conceptual model is an important item to be included in this section. Ideally, a SFM can be developed that captures all major feedback loops.

- **System Fragilities**: This section utilizes the conceptual model to identify and understand the fragilities of the system under consideration. Fragilities can by physical, chemical, biological, social, or economical in nature. They can by constitutional or related to processes. As much as possible, these fragilities are discussed quantitatively. The goal is to get a realistic, tangible and precise characterization of the fragilities. Importantly, which of these fragilities can be reduced through adaptation of the system? In most cases, a table will summarize the relevant fragilities.

- **Hazards and Threats**: This section considers the hazards the system may be exposed to including those hazards that may arise inside of the system. What are the hazards that constitute threats for the system considered? What system trends could lead to threats? In most cases, it is important to distinguish the exogenic hazards that are the result of global and regional processes and outside of the reach of the stakeholders in the location considered, and the endogenic hazards that can be address by the local stakeholders. This helps to answer the question of which of these hazards can be mitigated. Mapping the hazards often utilizes a probability versus impact diagram, which helps to identify those hazards associated with high risks. The section gives a comprehensive overview of the hazards, how they interrelate, and how they may change over time. The hazard probabilities are discussed as a function of hazard magnitude and described as hazard probability functions. Hazard scenarios are considered that can be used in the next section to develop foresight.

- **Foresight**: This section explores the spectrum of possible futures for the system under consideration. What is the full spectrum of possible futures for this system? Is there a prognosis and what does this prognosis look like? What are the risks that require some form of risk and resilience governance? What future challenges can be expected? A scenario-based approach with three or more different hazard scenarios can help to explore the spectrum of possible futures. What are the long-term consequences of the "no intervention" option? How are small-scale (local) and large-scale (global) processes impacting the system's current and future trajectory. What has been done to move the system towards desirable futures? What were the outcomes of these efforts?

- **Interventions and Options**: With this knowledge about the spectrum of possible futures and the goal statement, it is possible to consider a range of interventions that have the potential to direct the system towards a desirable future consistent with the goal statement. Risk assessments for each of the interventions considered provide important input for the decision process on which interventions to recommend. Questions to be addressed include: What are feasible options for interventions that would put the system on trajectories towards desirable futures? Are they addressing the problem through mitigation of the causes, managing and mitigating the impacts, or adapting the system to the changes. Are the options likely to increase the system's resilience and antifragility? Considering that wicked problems have no defined solution, only better or worse options, and most realistic options are not going to be simple, what are the practical advantages and disadvantages of competing options? Who are the potentially competing societal agents and what do they stand to gain/lose from each option. At least three options should be considered and the associated scenarios and potential system trajectories should be discussed. Importantly, the options considered here need to be consistent with the foresight developed in the previous section.

- **Discussion and Conclusions**: This section discusses the wicked problem with a main focus on the spectrum of possible futures and summarizes the main conclusions about the possible interventions.

- **Recommendations**: Based on the previous two sections, this section provides recommendations directed towards a well defined target group identified in Section 2 on how to address the issue and make progress towards a desirable future. The recommended transformative interventions must have a realistic potential to impact the future of the system in a desirable way. The recommendations are linked to the scenarios discussed in the sections on foresight and options. The recommendations clarify in detail to whom these recommendations are directed and who could play a major role in implementing them.

4.6 Practicalities for the Use of the Case Study Tool

On Place4Us, case studies can be carried out in *Virtual Community Centers (VCCs)* as part of participatory modeling projects. There, the report for each case study can be developed using a Web-based tool. This collaborative tool is designed for a group to work jointly on a report. The tool provides separate boxes for each section and allows to give each section a meaningful headline. The tool provides means to include a bibliography and to upload figures and tables. The case study tool includes many help pages to support the participants in this important step of preparing a scientifically sound and well written report.

For each case study, a group is set up, which includes the author(s) and additional members. At all stages, all group members can provide comments on each section, figure or table of the draft report. The authors can use the comment utility to ask questions to the group. Stakeholders can be included in groups as needed.

In most cases, the case study report is paired with an oral (promotional) presentation. In participatory modeling projects, the presentation is presented to stakeholders at a stakeholder meeting. The presentation can also be used to produce a promotional video.

For case studies in courses, a group includes at a minimum the author(s) and instructor(s). For case studies as part of an internship, representatives of the host institution are also included. In some courses, other students are included to provide a peer-to-peer reviewing of the case studies. In most cases, several versions can be submitted for formal comments and grading. In all courses, the students are asked to submit early on an outline, which is commented on by the instructors. In some course, a draft final is required and graded. The final is then prepared based on the comments received on the draft final. In the grading of the final, the degree to which the student responded to the comments received is taken into account.

For student case studies, the length of the oral presentation depends on whether the case study is carried out by individual students or groups of students. The goal for the presentation is to inform the audience (general public and peers) about the real-world issue and to convince the audience to care about it and act responsible. In most courses, the students are also asked to prepare a reflective video that covers the full promotional presentation. The videos should be between 5 and 10 minutes long and give a good overview of the case study and the outcomes, as well as reflections on the learning experience of carrying our the case study.

5 Discussion and Conclusions

The CST provides a powerful tool to structure case studies of wicked problems in a transdisciplinary participatory approach. The template takes a holistic approach to wicked problems within the framework of systems thinking.

The template was developed over the period from 2017 to 2024 with input from many students, federal and state agencies, a range of experts, and stakeholders in wicked problems. In education of sustainability leaders, the template has been used in more than 200 case studies. In many of these cases studies, when stakeholders were not available to participate, role playing exercises were used to explore stakeholders' view on the desired future. Outside of the class room the template has been used for about ten case studies. A main conclusion is that the template provides very helpful guidance ensuring active participation of stakeholders in a systems thinking framework.

Acknowledgements

The transdisciplinary participatory approach to wicked problems was developed within the Sustainability and Conservation Leadership Program at ODU. The author is grateful for contributions to the development of the *Case Studies in Sustainability (CSS)* by Tatjana Lobova and Eddie Hill (ODU), as well as Alisa Rawlins and Alison Sasnett (US Fish and Wildlife Service).

Acronyms

CSS Case Studies in Sustainability

CST Case Study Template

ELSS Earth's life-support system

SDG Sustainable Development Goal

VCC Virtual Community Center

References

A., V., Kolagani, N., McCall, M. K., Glynn, P. D., Kragt, M. E., Ostermann, F. O., Pierce, S. A., & Ramu, P., 2016. Modelling with stakeholders — next generation, *Environmental Modelling & Software*, **77**, 196–220.

Australian Government, 2007. Tackling wicked problems, Tech. rep., Australian Public Service Commission, Australian Government, Available at http://www.enablingchange.com.au/wickedproblems.pdf".

Avin, S., Wintle, B. C., Weitzdörfer, J., hÉigeartaigh, S. S. Ó., Sutherland, W. J., & Rees, M. J., 2018. Classifying global catastrophic risks, *Futures*, **102**, 20–26.

Baum, S. D., 2015. The far future argument for confronting catastrophic threats to humanity: Practical significance and alternatives, *Futures*, **72**, 86–96.

Beard, C. & Wilson, J. P., 2018. *Experiential Learning – A Paractical Guide for Training Coaching and Education*, Kogan Page Limited, New York, 4th edn.

Beer, S., 1985. *Diagnosing The System For Organizations*, John Wiley & Sons, New York.

Bengston, D. N., 2018. Principles for thinking about the future and foresight education, *World Futures Review*, **10**(3), 193–202.

Bengston, D. N., Kubik, G. H., & Bishop, P. C., 2012. Strengthening environmental foresight: potential contributions of futures research, *Ecology and Society*, **17**(2), 10.

Biggs, D., Abel, N., Knight, A. T., Leitch, A., & Langston, A. andBan, N. C., 2011. The implementation crisis in conservation planning: Could mental models help?, *Conservation Letters*, **4**, 169–183.

Bradshaw, C. J. A., Ehrlich, P. R., Beattie, A., Ceballos, G., Crist, E., Diamond, J., Dirzo, R., Ehrlich, A. H., Harte, J., Harte, M. E., Pyke, G., Raven, P. H., Ripple, W. J., Saltré, F., Turnbull, C., Wackernagel, M., & Blumstein, D. T., 2021. Underestimating the challenges of avoiding a ghastly future, *Frontiers in Conservation Science*, **1**, DOI: 10.3389/fcosc.2020.615419.

Brondizio, E. S., Settele, J., Díaz, S., & Ngo, H. T., eds., 2019. *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, IPBES Secretariat, Bonn, Germany.

Brown, V. A., Grootjans, J., Ritchie, J., Townsend, M., & Verrinder, G., 2005. *Sustainability and Health: Supporting Global Ecological Integrity in Public Health*, Earthscan, London.

Brown, V. A., Harris, J. A., & Russell, J. Y. (eds.), 2010. *Tackling Wicked Problems – Through the Transdisciplinary Imagination*, Earthscan, London, New York.

Brozovi¸̀, D., 2023. Societal collapse: A literature review, *Futures*, **145**, 103075.

Carpenter, S. R., Pingali, P. L., Bennett, E. M., & Zurek, M. B., eds., 2005. *Ecosystems and Human Wellbeing: Scenarios*, vol. 2 of **Millennium Ecosystem Assessment Reports**, Island Press, Washington.

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M., 2015. Accelerated modern human–induced species losses: Entering the sixth mass extinction, *Sci. Adv.*, **1**(e1400253), 1–5.

Ceballos, G., Ehrlich, P. R., & Dirzo, R., 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines, *PNAS*, pp. E6089–E6096, DOI: 10.1073/pnas.1704949114.

Clark, W. C. & Dickson, N. M., 2002. Sustainability science: the emerging research program, *Proceedings of the National Academy of Sciences*, **100**(14), 8059–8061.

Conklin, J., 2006. *Dialogue Mapping - Building Shared Understanding of Wicked Problems*, John Wiley and Sons LtD, Chichester.

Dreborg, K. H., 1996. Essence of backcasting, *Futures*, **28**(9), 813–828.

Ducot, C. & Lubben, G. J., 1980. A typology for scenarios, *Futures*, **11**(1), 51–57.

Garcia, C. A., Savilaakso, S., Verburg, R. W., Gutierrez, V., Wilson, S. J., Krug, C. B., Sassen, M., Robinson, B. E., Moersberger, H., Naimi, B., Rhemtulla, J. M., Dessard, H., Gond, V., Vermeulen, C., Trolliet, F., Oszwald, J., Quétier, F., Pietsch, S. A., Bastin, J.-F., Dray, A., Araújo, M. B., Ghazoul, J., & Waeber, P. O., 2020. The global forest transition as a human affair, *One Earth*, **2**(5), 417–428.

Garner, S. D., 2006. High-Level Colloquium on Information Literacy and Lifelong Learning — Bibliotheca Alexandrina, Alexandria, Egypt, November 6-9, 2005, Tech. rep., Sponsored by the United Nations Education, Scientific, and Cultural Organisation (UNESCO), National Forum on Information Literacy (NFIL) and the International Federation of Library Associations and Institutions (IFLA), Reported and Edited by Sarah Devotion Garner, J.D., M.L.I.S. Available at https://www.ifla.org/files/assets/information-literacy/publications/high-level-colloquium-2005.pdf.

Garnett, P., 2018. Total systemic failure?, *Science of The Total Environment*, **626**, 684 – 688.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., & Noble, I., 2013. Sustainable Development Goals for people and planet, *Nature*, **495**, 305–307.

Grunwald, A., 2015. Transformative Wissenschaft. Eine neue Ordnung im Wissenschaftsbetrieb?, *GAIA-Ecological Perspectives for Science and Society*, **24**(1), 17–20.

Guyot, P. & Honiden, S., 2006. Agent-based participatory simulations: merging multi-agent systems and role-playing games, *J Artificial Societies and Social Simmulations*, **9**(4), http://jasss.soc.surrey.ac.uk/9/4/8.html.

Harte, C., 2018. Land degradation now at a critical level warn experts, *Ecocologist*, pp. On–line publication, March 26, 2018, https://theecologist.org/2018/mar/26/land–degradation–now–critical–level–warn–experts.

Hatfield, A. J. & Hipel, K. W., 2002. Risk and systems theory, *Risk Analysis*, **22**(6), 1043–1057.

Henly-Shepard, S., Gray, S. A., & Cox, L. J., 2015. The use of participatory modeling to promote social learning and facilitate community disaster planning, *Environmental Science and Policy*, **45**, 109–122.

Hill, E., Zajchowski, C., Plag, H.-P., Lobova, T., & DeSoci, A., 2020. Assessing high-impact practices: The role of triple-loop learning in fostering future conservation leaders, *Journal of Outdoor Recreation, Education & Leadership*, **12**(2), 258–260.

Holmberg, J. & Robèrt, K. H., 2000. Backcasting from non-overlapping sustainability principles: a framework for strategic planning, *International Journal of Sustainable Development and World Ecology*, **74**, 291–308.

IPCC, 2018. Global warming of 1.5°C, Special report 15, Intergovernmental Panel on Climate Change, https://www.ipcc.ch/sr15/.

Jackson, I., 2008. Gestalt – a learning theory for graphic design education, *International Journal of Art & Design Education*, **27**(1), 63–69.

Kates, R., Clark, W. C., Hall, J. M., Jaeger, C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J., Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., Mooney, H., Moore III, B., O'Riordan, T., & Svedin, U., 2001. Sustainability science, *Science*, **292**(5517), 641–642.

Keynes, J. M., 1936. *The General Theory of Employment, Interest, and Money*, Macmillan.

Keys, P. W., Galaz, V., Dyer, M., Matthews, N., Folke, C., & Nyström, M.and Cornell, S. E., 2019. Anthropocene risk, *Nature Sustainability*.

Koch, C., 2019. *The Feeling of Life Itself — Why Consciousness is Widespread but Can't be Computed*, The MIT Press, Cambridge, Massachusetts.

Kuhlemann, K., 2019. Complexity, creeping normalcy and conceit: sexy and unsexy catastrophic risks, *Foresight*, **21**(1), 35–52.

Le Page, C., Abrini, G., Barreteau, O., Becu, N., Bommel, P., Botta, A., Dray, A., Monteil, C., & Souchere, V., 2011. Models for sharing representations, in *Companion Modelling: A participatory approach to support sustainable development*, edited by M. C. Etienne, pp. 69–96, Springer, Heidelberg.

Lebow, V., 1955. Price competition in 1955, *Journal of Retailing*, **31**(4), 5–10.

Levin, K., Cashore, B., Bernstein, S., & Auld, G., 2012. Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change, *Policy Sciences*, **45**(2), 123–152.

Mauser, M., Klepper, G., Rice, M., Schmalzbauer, B. S., Hackmann, H., Leemans, R., & Moore, H., 2013. Transdisciplinary global change research: the co-creation of knowledge for sustainability, *Current Opinion in Environmental Sustainability*, **5**(3–4), 420–431.

Mercier, H. & Sperber, D., 2017. *The Enigma of Reason*, Harvard University Press, Cambridge, Massachusetts.

Miller, T. R., 2013. Constructing sustainability science: emerging perspectives and research trajectories, *Sustainability science*, **8**(2), 279–293.

Miller, T. R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D., & Loorbach, D., 2014. The future of sustainability science: a solutions-oriented research agenda, *Sustainability science*, **9**(2), 239–246.

Moss, R. H., Meehl, G. A., Lemos, M. C., Smith, J. B., Arnold, J. R., Behar, D., Brasseur, G. P., Broomell, S. B., Busalacchi, A. J., Dessai, S., Ebi, K. L., Edmonds, J. A., Furlow, J., Goddard, L., Hartmann, H. C., Hurrell, J. W., Katzenberger, J. W., Liverman, D. M., Mote, P. W., Moser, S. C., Kumar, A., Pulwarty, R. S., Seyller, E. A., Turner II, B. L., Washington, W. M., & Wilbanks, T. J., 2013. Climate change - hell and high water: practice-relevant adaptation science, *Science*, **342**, 696–698, DOI: 10.1126/science.1239569.

Neugarten, M. L., 2016. Foresight – are we looking in the right direction?, *Futures*, **38**(8), 894–907.

Plag, H.-P., 2020. Modern climate change: A symptom of a single-species, high energy pulse, in *Moral Theory and Climate Change: Ethical Perspectives on a Warming Planet*, edited by D. E. Miller & B. Egglestone, pp. 6–34, Taylor and Francis/Routledge.

Plag, H.-P. & Jules-Plag, S.-A., 2017. An economy for humanity: Transition to an economy for a thriving humanity and planetary future, *ApoGeoSpatial*, **32**(2, Spring 2017), 30–35.

Plag, H.-P. & Jules-Plag, S.-A., 2019. A goal-based approach to the identification of essential transformation variables in support of the implementation of the 2030 Agenda for Sustainable Development, *International Journal of Digital Earth*, **13**(2), 166–187, DOI: 10.1080/17538947.2018.1561761.

Plag, H.-P., Khalsa, S. J., & Pearlman, P., 2017. Creating pathways to a sustainable future, *OES Beacon*, **6**(1), 29–30.

Rittel, H. W. J. & Webber, M. W., 1973. Dilemmas in a general theory of planning, *Policy Sciences*, **4**, 155–169.

Roberts, N., 2000. Wicked problems and network approaches to resolution, *International Public Management Review*, **1**(1), http://journals.sfu.ca/ipmr/index.php/ipmr/article/view/175.

Robinson, J. B., 1988. Unlearning and backcasting: Rethinking some of the questions we ask about the future, *Technological Forecasting and Social Change*, **33**(4), 325–338.

Robinson, J. B., 1990. Futures under glass: a recipe for people who hate to predict, *Futures*, **22**(8), 820–842.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S. I., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., & Foley, J., 2009. A safe operating space for humanity, *Nature*, **461**, 472–475.

Scholes, R., Montanarella, L., Brainich, A., Barger, N., ten Brink, B., Cantele, M., Erasmus, B., Fisher, J., Gardner, T., Holland, T. G., Kohler, F., Kotiaho, J. S., Von Maltitz, G., Nangendo, G., Pandit, R., Parrotta, J., Potts, M. D., Prince, S., M., S., & Willemen, L., eds., 2018. *Summary for policymakers of the thematic assessment of land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, IPBES secretariat, Bonn, Germany.

Smith, A., 1776. *An Inquiry into the Nature and Causes of the Wealth of Nations. Volume 1*, W. Strahan, London.

Soergel, B., Rauner, S., Daioglou, V., Weindl, I., Mastrucci, A., Carrer, F., Kikstra, J., Ambrósio, G., Dutra Aguiar, A. P., & Baumstark, l., 2024. Multiple pathways towards sustainable development goals and climate targets, *Environ. Res. Lett.*, **19**(12), 124009 DOI 10.1088/1748–9326/ad80af.

Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., Summerhayes, C. P., Barnosky, A. D., Cornell, S. E., Crucifix, M., Donges, J. F., Fetzer, I., Lade, S. J., Scheffer, M., Winkelmann, R., & Schellnhuber, H. J., 2018. Trajectories of the earth system in the anthropocene, *Proceedings of the National Academy of Sciences*, **115**(33), 8252–8259.

Taleb, N. N., 2012. *Antifragile - Things that gain from disorder*, Random House, Inc., New York.

Tonn, B. & Stiefel, D., 2014. Human extinction risk and uncertainty: Assessing conditions for action, *Futures*, **63**, 134–144.

United Nations, 2015. Transforming our world: The 2030 agenda for sustainable development, Tech. Rep. A/RES/70/1, United Nations.

Utting, P., 2013. Pathways to sustainability in a crisis-ridden world, in *Reducing Inequalities: A Sustainable Development Challenge*, edited by G. Rémi, R. K. Pachauri, & L. Tubiana, TERI, New Delhi.

Vucetich, J. A., Bruskotter, J. T., & Nelson, M. P., 2015. Evaluating whether nature's intrinsic value is an axiom of or anathema to conservation, *Conservation Biology*, **29**(2), 321–332.

Wiek, A., Ness, B., Schweizer-Ries, P., Brand, F. S., & Farioli, F., 2012. From complex systems analysis to transformational change: a comparative appraisal of sustainability science projects, *Sustainability Science*, **7**, 5–24.

Wiggins, G. & McTighe, J., 2005. *Understanding by Design*, Association for Supervision and Curriculum Development, Alexandria, Va., 2nd edn.