Science in Society Series

RECONSTRUCTING SUSTAINABILITY SCIENCE

KNOWLEDGE AND ACTION FOR A SUSTAINABLE FUTURE

THADDEUS R. MILLER

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Reconstructing Sustainability Science

The growing urgency, complexity and 'wickedness' of sustainability problems – from climate change an biodiversity loss to ecosystem degradation and persistent poverty and inequality – present fundament challenges to the production and use of scientific knowledge. While there is little doubt that science has crucial role to play in our ability to pursue sustainability goals, critical questions remain as to how organize research most effectively and connect it to actions that advance social and natural well-being.

Drawing on interviews with leading sustainability scientists, this book examines how researchers the emerging, interdisciplinary field of sustainability science are attempting to define sustainabilit establish research agendas and link the knowledge they produce to societal action. Pairing these insigh with case studies of innovative sustainability research centres, the book reformulates the sustainabili science research agenda and its relationship to decision-making and social action. It repositions the fie as a 'science of design' that aims to enrich public reasoning and deliberation while also working generate social and technological innovations for a more sustainable future.

This timely book gives students, researchers and practitioners a valuable and unique analysis of th emergence of sustainability science, and both the opportunities and barriers faced by scientific efforts contribute to a more sustainable world.

Thaddeus R. Miller is Assistant Professor at the Nohad A. Toulan School of Urban Studies and Plannin and a Faculty Fellow at the Institute for Sustainable Solutions at Portland State University, USA. He also an affiliate of the Consortium for Science, Policy, and Outcomes at Arizona State University, USA His research explores the social, ethical and political dimensions of science, technology and sustainability

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Knowledge and action for a sustainable future
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RECONSTRUCTING SUSTAINABILITY SCIENCE

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To Britt and Zadie

‘A new generation of students and scholars has embraced sustainability as a concept and is eager t
ex~~plore more thoughtful, more integrative and better scientifically grounded ways to approach it~~. Tha
Miller’s new book is just what they are looking for.’

Paul B. Thompson, Michigan State University, US

‘Thad Miller’s book presents a sophisticated, nuanced and insightful analysis of the emerging field
sustainability science. Particularly welcome is his analysis of the normative, ethical and epistemologic
underpinnings of different approaches to sustainability. His proposal for an explicitly normativ
solutions-oriented approach to sustainability is exactly right.’

John Robinson, University of British Columbia, Canad

‘Thad Miller, in this new conceptualization of how to restructure for sustainability science, outlines th
logic and mechanisms by which an action-oriented, outcome-driven science might emerge. His boo
serves as a guide for what all sophisticated future-oriented knowledge enterprises should have as a pa
of their teaching, learning and discovery agendas in order to pursue a more sustainable future.’

Michael M. Crow, Arizona State University, US

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PREFACE

In the spring of 2007, I was among a handful of graduate students to enroll in the inaugural class of th first School of Sustainability at Arizona State University. We had in common a deep concern for the sta of our planet's ecology and its implications for human well-being, a desire to do something about th and a collective excitement to be a part of a new program. Self-proclaimed guinea pigs, we eager signed up for this somewhat radical experiment in the reorganization of research and education understand and address the complex problems of sustainability.

The School of Sustainability is on the bleeding edge of efforts to transform our research and educatio institutions to break down disciplinary divides and tackle real-world sustainability problems. From th University of Tokyo to Stellenbosch University in South Africa and, my current home, Portland Sta University, universities around the globe are shifting to reshape research and education in the face rapid global environmental change. As they do so, they reveal the limitations of traditional disciplina approaches and the barriers to transformative change in academia (Crow 2010; Miller ***et al***. 2008).

In these changes and others, including the National Science Foundation's recent Science, Engineerin and Education for Sustainability initiative and the International Council for Science (ICSU) ***Future Eart*** there is a recognition that the ways in which we have come to organize research and education limit o ability both to understand and resolve sustainability problems. The challenges and roadblocks run fro the seemingly mundane – such as how the distribution of student credit hours impedes interdisciplina course offerings – to deep normative and epistemic divides between academic disciplines an assumptions about the relationship between scientific knowledge and social action.

Being a naïve yet willing participant in this upheaval as a doctoral student, I became interested understanding how sustainability challenges were reshaping academic programs and emergi interdisciplinary fields. How are disciplines merging? How are the normative goals of sustainabili incorporated into supposedly 'value-free' scientific research? How will the knowledge produced b sustainability research be utilized? How are sustainability problems framed? By whom? For m dissertation research, I took up these questions and others to examine the emergence of sustainabili science – an interdisciplinary, problem-driven field at the forefront of efforts by the US Nation Academies of Science and the American Association for the Advancement of Science to address rea world sustainability problems. Sustainability and scientific efforts to contribute to it are rich territory f analyzing the complex interplay between science and society and how scientists are responding twenty-first century sustainability challenges.

At the core of these and similar efforts is a critical question: How can science and technology mo effectively inform and foster social action for sustainability? How is knowledge to be connected actions and decision making that advance collective visions of natural and social well-being (Bockin 2004; Jasanoff 1997)? This book examines how sustainability science aims to contribute to social action f sustainability and the implications of emerging research agendas for societal discourse on sustainabilit The results will help move sustainability science forward through a better understanding of how scien might contribute to social outcomes more effectively. It will provide an opportunity to create mo reflexive sustainability science research agendas and demonstrate the necessity of addressing the soci political and normative dimensions of sustainability in order to contribute to social action. I hope to la the foundation for a sustainability science that is evaluated based on its ability to frame sustainabili problems and solutions in ways that make them amenable to democratic and pragmatic social action.

~~This book has also been a deeply personal project. It began with reflections on what kind of stude~~ the School of Sustainability was trying to produce. How would we – those guinea pigs – be differen How can places like the School of Sustainability contribute to more sustainable communities? How w these experiments change the way we organize research and education institutions? These initi reflections transformed into my research agenda owing in large part to an incredibly fruitful and creati intellectual environment at Arizona State – particularly around the School of Sustainability, the NS Integrative Graduate Education and Research Training (IGERT) program in Urban Ecology and th Consortium for Science, Policy, and Outcomes (CSPO).

After receiving my doctorate in Sustainability in Spring 2011, I accepted my current position Assistant Professor in the Nohad A. Toulan School of Urban Studies and Planning at Portland Sta University. Portland State has made sustainability one of its campus-wide strategic initiatives. At Portlar State, this effort is led by the Institute for Sustainable Solutions, where I am now a Faculty Fellov Faculty, administration, staff and students at universities around the world are actively working t transform research and education to produce knowledge, technologies and people that will meet th challenges of sustainability. Arizona State, Portland State and other colleges and universities I'v encountered in my research and through colleagues have met their fair share of barriers as well successes. From this work and experience, it is clear that sustainability's 'wicked' problems (which discuss in Chapter 1) present fundamental challenges to knowledge production and our ability to lir research to beneficial outcomes.

This project is the result of empirical and theoretical research and deep personal and profession reflection on these challenges. It creates an opportunity for the emergence of a more reflexiv sustainability science and demonstrates the necessity of addressing the social, political and normati dimensions of sustainability in order to contribute to social action. The ongoing transformations research and education for sustainability throughout the world make this an especially exciting time be involved in this work. However, the challenges are significant and carry risks for the students, facul and administration involved. This book contributes to our understanding of the successes and limitatio of such transformations and develops a pathway forward for a more radically interdisciplinary, solution oriented design science for sustainability.

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This project began as my dissertation project as a doctoral student at Arizona State University's School Sustainability. If the dissertation process were not long and arduous enough, the long haul to th manuscript was that and more. Throughout this project, I have been incredibly lucky to have the suppo and cooperation of many colleagues, friends and family. Though long, it has been a socially ar intellectually rewarding process.

First, I would like to thank all of those I interviewed throughout the course of my research for the responsiveness and for their generosity with their time. One of the highlights of my work has been th opportunity to meet such intelligent and dedicated individuals and discuss the core problems sustainability.

This research would not have been possible without funding from the National Science Foundatio Integrative Graduate Education and Research Training Program (IGERT), the Graduate Stude Professional Association at Arizona State University and the Institute for Sustainable Solutions at Portlar State University. This material is based upon work supported by the National Science Foundation unde Grant No. 0504248, IGERT in Urban Ecology. Any opinions, findings and conclusions or recommendatio expressed in this material are those of the author and do not necessarily reflect the views of the Nation Science Foundation.

The IGERT Program in particular and the opportunities it affords have been instrumental in m development as a scholar. I would like especially to thank the IGERT Principal Investigators, Stua Fisher, Ann Kinzig, Margaret Nelson and Charles Redman, as well as the program administrator, Ga Ryser, for all of their help and support throughout my time as an IGERT Fellow.

As a graduate student at Arizona State University, I was fortunate to be surrounded by a group intelligent, dynamic and committed students and faculty, particularly in the IGERT Program, the Scho of Sustainability and the Consortium for Science, Policy and Outcomes (CSPO). I would like particularly thank the following colleagues for their input and support: Kate Darby, Ann Kinzig, Cla Miller, Tischa Muñoz-Erickson, Mark Neff and Zachary Pirtle.

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Last, but certainly not least, I would like to thank my family for their support and enthusiasm. T Mom, Dad and Cam for checking in with words of encouragement and, sometimes, incomprehensio Most especially, my wife, Britt Crow-Miller, has helped me through this in more ways than she know Not only is she a great editor but, more importantly, she is tolerant, loving, supportive – and a gre travel companion on research trips. This process has been long enough to see us get married ar welcome our daughter, Zadie Avalyn Miller, into the world. And to Zadie – thank you for showing m

what matters in life.

~~As usual, all faults are my own, and everything worthwhile is in part a result of working~~ with tho
mentioned above.

PART I

Constructing sustainability science

1

PLANET UNDER PRESSURE

In the spring of 2012, during a run of unseasonably warm weather, 3,000 scientific experts and decisio makers gathered in London at the 'Planet under Pressure: New Knowledge towards Solution conference. Convened by the Global Environmental Change Programmes and the International Coun for Science, the goal of the conference was 'to assess the state of the planet and explore solutions impending global crises' (Brito and Smith 2012: 1). 'Planet under Pressure' was timed to deliver powerful message to the United Nations Conference on Sustainable Development, or Rio+20, to be he that summer. The 'State of the Planet Declaration', summarizing the key messages from the proceeding was issued at the conference. The declaration provided a clear and urgent call to global action to me the world's sustainability challenges. New scientific understandings of the Earth system, it declare 'demand a new perception of responsibilities and accountabilities of nation states to support planeta stewardship' (ibid.: 2). Recent research and the large-scale action required by society, urge the authors the declaration, require drastic changes in political and scientific organization:

> The scientific community must rapidly reorganize to focus on global sustainability solutions. W must develop a new strategy for creating and rapidly translating knowledge into action, which w form part of a new contract between science and society, with commitments from both sides
>
> ***(ibid.:** 4*

I begin with this brief dispatch from London to illustrate the ways in which scientific discourse an knowledge claims, particularly around sustainability concerns, are intertwined with socio-political an normative claims and visions of social, political and ecological order. This gathering of scientific delegat sought to bring the power of scientific knowledge to bear on the social and political barriers to achievin sustainability. Insights provided by scientific knowledge, according to the Declaration, are a cause reconsider our ethical and moral positions. In this case, a call for 'planetary stewardship' that requir radical changes to social and political organization to be put into practice. Both normative claims abo what we ***ought*** to value and how, and visions of social and political order – 'interconnected problem require interconnected solutions' (ibid.: 2) – are positioned as stemming from insights gained throug acquisition of scientific knowledge.

The Declaration contends that financial and political support for a reorganization of scientific researc are necessary. Knowledge must be more rapidly generated and translated to social and political actio This requires a focus on solutions to global sustainability by scientists. They cite the International Coun for Science ***Future Earth*** research initiative, which will 'develop the knowledge… for supportin transformation toward global sustainability' (Future Earth 2013), as the type of support and organizati that is needed. Global sustainability challenges, then, should drive changes in research organization an priorities and to the more effective use of scientific knowledge.

Scientific discourse and knowledge making are inextricably linked to visions of social, political an ecological order (Jasanoff 2010; Latour 1988). The State of the Planet Declaration and the proceedings the ‘Planet under Pressure’ conference demonstrate how knowledge claims about the sustainability o ~~interconnected, socio-ecological systems are also claims to the proper social, political and scientif~~ organization that is necessary to promote sustainability. These knowledge claims are also claims to norn and values that ought to be pursued and upheld. This relationship between science and society is n unique to the sustainability arena and has been explored extensively by science and technology studi (STS) scholars (e.g. Jasanoff 2005; Latour 2004; Shapin and Schaffer 1985). Science produces beliefs n only about how the world is, but also how it ***ought*** to be (Jasanoff 2004; Latour 1993). As scientis describe social or ecological dynamics, they influence beliefs about what dynamics are sustainable – wh society ***ought*** to do in order to be sustainable. Scientists attempt to respond to social and environment concerns by researching problems identified by society as important. How sustainability scien influences the social, political and normative dimensions of sustainability may render the concept sustainability and the problems it encapsulates more or less tractable in terms of social action.

Sustainability challenges are reshaping scientific research and education at multiple scales, yet glob science and policy organizations and national and regional research and education institutions are i equipped to deal with integrative knowledge generation and the management of complex science policy interfaces (Crow 2007; Reid ***et al***. 2010; Miller ***et al***. 2011). From well-established disciplines suc as ecology and geography to emerging, interdisciplinary fields such as earth systems science an sustainability science, scientists are moving to find ways to contribute more directly to the resolution society’s most pressing problems (Lubchenco 1998; NRC 1999). Central to these efforts is the followi question: How can science and technology inform and foster social action for sustainability? Or, p slightly differently, how is scientific knowledge to be connected to actions and decision making th advance our visions of natural and social well-being?

This question has spawned a variety of efforts by members of the scientific community to contribute the resolution of pressing social and environmental problems (Lubchenco 1998; NRC 1999; Palmer ***et a*** 2005; Reid ***et al***. 2010). Perhaps the most prominent and wide-ranging of these efforts, and the one th this book will focus on, has been sustainability science – an interdisciplinary, problem-driven field th addresses fundamental questions on human – environment interactions (Clark 2007; Clark and Dickso 2003; Kates ***et al***. 2001; Levin and Clark 2010). Sustainability scientists aim to support sustainabili transitions by linking scientific knowledge to societal action (Cash ***et al***. 2003; Clark and Dickson 200 The field is both problem-oriented and ‘focus[ed]… on understanding the complex dynamics that aris from interactions between human and environmental systems’ (Clark 2007: 1737). Carpenter ***et al***. (200 1305) note that sustainability science ‘is motivated by fundamental questions about interactions of natu and society as well as compelling and urgent social needs.’ They define progress in sustainability scien as those areas where ‘scientific inquiry and practical application are comingled.’ Carpenter ***et al***. (200 go on to stress ‘the urgency and importance of an accelerated effort to understand the dynamics coupled human – natural systems.’ This argument is representative of a major theme in sustainabili science: The fundamental understanding of the dynamics of human – environment interactions (e. Turner ***et al***. 2003a, b).

Sustainability and scientific efforts to contribute to it are rich territory for analyzing the comple interplay between science and society and examining how scientists are responding to twenty-fi century sustainability challenges. This analysis, then, will provide insight into how to develop a mo effective role for science in pursuing sustainability goals. Utilizing theories and insights from STS, th book explores the construction of a new, and to some, radically interdisciplinary, use-inspired field scientific research – sustainability science. Sustainability science provides an important window throu which to examine how scientific knowledge production – its organization and institutions – are bei (re)shaped to respond to complex, urgent and value-laden problems related to sustainability. Throug ~~interviews and discourse analysis, I explore how sustainability scientists perform boundary work~~ (Giery 1983), establishing credibility and epistemic claims and demarcating areas of normative and soci political concern. This will contribute to STS analyses of the relationship between science and society well as inform developments in sustainability science and allied fields. In so doing, the purpose is not simply critique sustainability science, but to lay the foundation for a deeper dialogue among sustainability scientists, decision makers and other concerned stakeholders over the role of science sustainability and future directions for the field.

This book will also explore the implications of transforming the contested and value-laden concept sustainability into the subject of fundamental scientific analysis. Sustainability can act as a platform f communities to articulate visions of social and natural well-being, including responsibilities to nature ar future generations (Norton 2005; Thompson 2010). In its broadest sense, one can view sustainability as a effort to formulate visions of the collective good. Science has, on one hand, brought many environment problems to the world's attention, including ozone depletion, acid rain and climate change, which have turn become the subject of normative and political concern. On the other hand, in offering objective ar epistemically powerful explanations of natural phenomena, science can also constrain what is consider appropriate, legitimate or necessary discourse and debate. Exploring these issues, this work w contribute to our understanding of the complex relationship between science and the normati dimensions of sustainability and point to areas where dialogue may be 'opened up' to allow f discussion of alternative pathways to and meanings of sustainability (Stirling 2008).

Finally, I will explore the following question: How can science shift from identifying and describin problems in the biophysical realm to contributing to potential solutions in the social and political realn It is this issue as well as the nature of sustainability problems as complex and contested that challeng the practice of sustainability science and its usefulness. In Part II, I develop a framework that push sustainability science toward focusing on the study and design of solutions, rather than the identificati of problems. This is a new, explicitly normative vision of sustainability science that, I argue, will be mo effective in advancing visions of natural and social well-being.

Before reviewing the structure of the book, I briefly discuss how the ***wickedness*** of sustainabili problems presents specific challenges to the production and utilization of scientific knowledge, and ho this analysis can provide an opportunity for sustainability science to address these challenges mo effectively.

Wicked sustainability

Sustainability issues are often ***wicked*** – that is, they are problems the solutions to which are not obviou wherein complexity is high, uncertainty is rampant, values are in dispute and trade-offs are the nor (Funtowicz and Ravetz 1993; Miller ***et al***. 2011; Rittel and Webber 1973). Many of the problems that fa under the rubric of sustainability – ensuring adequate access to clean water supplies, developi alternative energy systems, evaluating intergenerational trade-offs in natural resource use, and advanci solutions to widespread poverty – not only are difficult to define but rarely yield to simple, one-tim solutions. As the coiners of the term, Rittel and Webber (1973: 161) note: 'The formulation of a wicke problem ***is*** the problem! The process of formulating the problem and of conceiving a solution (or r solution) are identical, since every specification of the problem is a specification of the direction in whi a treatment is considered.'[1] Tame or benign problems, on the other hand, are those in which the goal clear and it is easy to determine whether the problem has been solved (Norton 2005; Rittel and Webbe 1973). ~~Often, as we will see below, tame problems may be amenable to scientific or technological~~ fixes.

Wicked problems are not just empirically challenging, they are linked to normative criteria (Fisch 2000; Hoppe and Peterse 1993). A central characteristic of such problems is that they are defined by valu pluralism and that these values are highly contested. Consensus over problem definitions or th identification of solutions is very difficult. In the case of tame or benign problems, convergence on polic and technical solutions is possible in part because the proposed solutions can satisfy multiple valu positions (at least for a time). In other words, wicked problems are just as political as they are scientific technical. In order to understand such problems conceptually, we must consider how scientific technical inputs allow for or impede the convergence of divergent and conflicting values on pathwa that lead to resolution, even if it is momentary or unstable.

Richard Nelson's (1977) moon and the ghetto metaphor highlights why distinguishing between tan and wicked problems is critical. Though technologically complicated, landing on the moon is a relativel tame problem. The mission is straightforward and it is clear when the objective has been achieved. It is matter of economic investment and technological capability. Success here is a testament to the capaciti of science and technology to solve such problems. When there is broad agreement on the nature of th problem and what will comprise a satisfactory solution, science and technology can be powerful tools inform our decisions and generate action (Allenby and Sarewitz 2011).

Nelson then asks, '[i]f we can land a man on the moon, why can't we solve the problems of th ghetto?' The problems of the ghetto are difficult to define and rarely give way to scientific technological applications. How can we provide decent and affordable health care? How can high scho graduation rates be improved? Addressing these issues is infinitely more complex. The solutions to suc problems are often highly contextual and contingent on social, cultural, political and economic factors. order to understand how science and technology might contribute to sustainability, scientists, engineer practitioners and decision makers would do well to consider the degree to which a given problem more like the moon or the ghetto – that is, is it amenable to a technological solution or does the proble lie in socio-political complexity? If the latter, are there elements of the issue that might be clarified wi additional scientific knowledge?

This should not, however, be taken to mean that technological solutions are always overly simplistic insufficient since they are perceived, particularly by the environmentalist community, as avoiding mor meaningful value changes. In fact, as Sarewitz and Nelson (2008) illustrate, so-called technological fix can be incredibly effective in enhancing human well-being and achieving specific and agreed goals. Th challenge is not to avoid technological solutions in favor of genuine changes in values and worldview instead, it is to understand the problem context and what solution pathways – from technological fix (which are rarely as simple as the critics would have one believe) to the long, but perhaps mo meaningful, slog of social and political change – are most appropriate and effective in achieving desirab outcomes.

Many of the environmental problems that society has been successful in solving to some degree hav been tame. Sewage treatment facilities and sanitation networks led to vast improvements in wat quality and public health throughout western Europe and North America in the mid-nineteenth centu (Melosi 2008). Likewise, the invention and eventual widespread use of the catalytic converter in the 195 and 1960s substantially reduced the toxicity of automobile emissions, contributing to improve air quali in heavily congested cities. A key point is that these tame problems are amenable to technic applications that are relatively uncontroversial and help to settle potential value debates. This is possib because the goal is clear and does not involve significant trade-off between various interests (Lindblo

1959). For wicked problems, this process is not possible. Potential technological or policy solutions t ~~wicked problems such as climate change often divide as many interests as they bring togethe~~ Furthermore, owing to normative and empirical complexity, solutions to wicked problems often end u leading to the proliferation of additional, unforeseen problems (Latour 1993; Scott 1998).

Yet it is also the case that, before modern sewage and sanitation systems, the problems of water-born disease, water quality and public health were wicked.[2] This is an example in which a wicked proble was tamed by technological developments, political will and institutional change. Such developments ca occur in the absence of necessary scientific understanding or even despite incorrect scientif understandings. For example, in the case of sanitation the miasmatic theory, which associated disea with bad smells, dominated contemporary thinking as new methods for sanitation and disease preventio were first implemented.

Additional scientific knowledge may not necessarily be the tool to help solve or settle a wicke problem. Calls for mode-2 knowledge production (Nowotny ***et al.*** 2001) and post-normal scien (Funtowicz and Ravetz 1993) have recognized and thoughtfully explored this dynamic. In fact, addition knowledge will likely be contested by conflicting scientific findings or political positions and reve additional uncertainties, rather than eliminating them (Sarewitz 2004). To what degree does sustainabilit science grapple with these issues? How do sustainability scientists navigate normative and epistem issues at the science – policy interface and then address the social, political and ethical challenges pose by sustainability problems? Sustainability science serves as an example to explore how far sustainabili concerns are reshaping scientific research agendas, if at all. If sustainability scientists are to facilita social learning and link knowledge to action, they must be able to differentiate between these vario types of problems and provide the knowledge or tools appropriate for a given context. This boo analyzes how sustainability scientists currently approach these dynamics and develops a framework f the field that incorporates these insights.

Book structure

The point of departure for this analysis is itself an openly normative one – sustainability is a valuable an value-laden concept that may allow communities and society writ large to articulate and represe visions of human and natural well-being. In a search for a new path for progress, sustainability lin concerns for the value(s) of nature, social justice and poverty with responsibilities to future generations. attempts to demarcate a desirable space in which humans would like to exist; a path in which socie should develop in a way that limits the negative human impacts (or even seeks to produce positiv impacts) on ecological support systems, reduces social injustices such as hunger and poverty, and takes long-term, multigenerational perspective. Sustainability is a normative claim about how the world is (i unsustainable) and how it ***ought*** to be. Sustainability offers the potential for constructing a new an improved discourse for discussion of environmental problems because it is both descriptive an evaluative (Norton 2005). As Norton (2005) argues, it is a ‘thick’ concept that can encapsulate a great de of information about how humans interact with the environment and present that information in a wa that is transparent, important to widely held social values and helps move communities toward adoptin more sustainable practices.

The book is organized in two parts. The first – Chapters 2, 3 and 4 – is an empirical and theoretic analysis of the emergence of sustainability science. Chapter 2 provides a detailed discussion of th theoretical and methodological approach taken in the book, drawing mostly from STS. It also provides brief overview of the emergence of sustainability science. Chapter 3 discusses the results of 28 in-dep interviews conducted with leading sustainability scientists. This chapter draws from a content analysis the relevant literature in sustainability science, examining how scientists are constructing resear agendas for sustainability. More specifically, it addresses three core questions: (1) How do sustainabili scientists define and bound sustainability? (2) How and why are various research agendas bei constructed to address these notions of sustainability? (3) How do scientists see their resear contributing to societal efforts to move toward sustainability? Following Thomas Gieryn's (1983, 199 concept of boundary work, this chapter analyzes how sustainability scientists demarcate areas normative, epistemic and socio-political concern.

Based on these results, Chapter 4 explores the tensions that arise between the approach sustainability scientists and societal efforts to articulate and pursue sustainability goals, addressing thre sets of questions: (1) How does sustainability science address the normative commitments of t sustainability discourse? What are the implications for science and for societal understandings sustainability? (2) What are the epistemic challenges posed by sustainability problems? How do sustainability science address these? (3) What are the barriers to and opportunities for linking knowled with action for sustainability? How does sustainability science as a field address these issues? The purpo of this analysis is to illuminate these often hidden tensions so that future research efforts in sustainabili science might navigate them more effectively and contribute to positive social outcomes.

Based on the empirical and conceptual work done in Part I, Part II maps out an alternative, or perha complementary, pathway for sustainability science. Chapter 5 marks a shift from the empiric exploration of sustainability science to this conceptual project. It examines the epistemic and normati limitations of scientific approaches to sustainability in order to open the pathway for a framewo centered on the articulation and pursuit of shared visions of social and natural well-being.

Chapter 6 borrows from the work of Nobel Laureate Herbert Simon and repositions sustainabili science as a 'science of design' – that is, a normative science of what ***ought*** to be in order to achie certain goals – rather than a science of what ***is***. It will develop a foundation for a sustainability scien that is solutions-oriented – one that aims to enrich public reasoning and deliberation while also worki to generate social and technological innovations for a more sustainable future. This chapter then develo a set of design imperatives for sustainability science that aim to overcome the limitations of oth approaches and focus research on the generation of positive, more sustainable, social outcomes. sustainability science of design requires thinking beyond the current state of affairs to explore ho preferred, more sustainable, futures can be developed and pursued. This requires that we rethink resear priorities, the role of science in society and the training of the next generation of sustainability scientists

Finally, Chapter 7 concludes with a discussion of the implications of a design science for sustainabilit for how we organize research agendas, knowledge-producing organizations and the relationship betwe science and society. As environmental philosopher Dale Jamieson (1998: 191) aptly notes, '[w]hat needed are simple and compelling stories that show us how to practically participate in creating t future in our daily lives, and how to engage in ongoing dialogue with others about how our everyd actions help to produce global realities.' Science alone cannot ***make*** a future happen; yet, it can help identify the potential implications of such futures and their plausibility. As various research agendas f sustainability continue to emerge and develop, this project offers an opportunity to consider how scien is informing and shaping societal efforts to pursue sustainability and an avenue for a more broad reflexive and deliberative research program for sustainability regarding how knowledge is appropriat and the public purposes it serves.

Notes

1 Rittel and Weber (1973) identify ten distinguishing characteristics of wicked problems: (1) There is no definitive formulation of a wick problem; (2) wicked problems have no stopping rule; (3) solutions to wicked problems are not true-or-false, but good-or-bad; (4) there no immediate and no ultimate test of a solution to a wicked problem; (5) every solution of a wicked problem is a 'one-shot operatio (6) wicked problems do not have enumerable (or an exhaustively describable) set of potential solutions; (7) every wicked problem essentially unique; (8) every wicked problem can be considered to be a symptom of another problem; (9) the existence of a discrepan representing a wicked problem can be explained in numerous ways; the choice of explanation determines the nature of the problem resolution; and (10) the planner has no right to be wrong.

2 Of course, such problems are ***still*** wicked in many parts of the world. In large part the contextual variability of problems and t differential presence of technology, know-how and the institutions necessary to regulate or deal with such problems can determi whether a problem is wicked or not. Whether a problem is tame or wicked is contextual.

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