Sustainable Development:
A course linking science with practice*
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This course explores how the peoples of an increasingly stressed planet earth can achieve better lives for themselves, their neighbors, and their posterity. Our focus is on the long-term, large-scale pathways of human development that emerge from the intertwined systems of nature and society that characterize our planet today in what some have called its "Anthropocene" epoch. In particular, we address two pernicious attributes of current development pathways: 1) they are achieving their many gains in ways that degrade the resources (natural and social) on which future prosperity depends; 2) they are fundamentally inequitable: a privileged minority improves their lives while limiting opportunities for everyone else—particularly today's poor and vulnerable communities, as well as future generations. The course seeks to understand how these ills can be remedied through collaborative actions and capacity building efforts that support the transition to more just and sustainable pathways of development. It does so via the systematic exposition of a theoretical framework grounded in sustainability science, that is then used to analyze a series of in-depth case studies in sustainable development prepared especially for the course.

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Unit 0.0 Overview: What is this course all about?

Objectives of the course

This course explores how the peoples of an increasingly stressed planet earth can achieve better lives for themselves, their neighbors, and their posterity. Our focus is on the long-term, large-scale pathways of human development that emerge from the intertwined systems of nature and society that characterize our planet today in what some have called its "Anthropocene" epoch. In particular, we address two pernicious attributes of current development pathways: 1) they are achieving their many gains in ways that degrade the resources (natural and social) on which future prosperity depends; 2) they are fundamentally inequitable, with a privileged minority achieving better lives for themselves but only by limiting the ability of everyone else – especially of poor and otherwise vulnerable communities alive today and all future generations – to better their own lives. The course seeks to understand how these ills can be remedied through collaborative actions and capacity building efforts that support the transition to more just and sustainable pathways of development.

The course will equip you to serve as a "general practitioner" supporting the pursuit of sustainability. In particular, you will learn concepts and skills that have proven useful for helping citizens, corporations, governments, and other social actors to:

- Articulate shared goals for sustainable development of the nature-society system in which they live;
- Assess progress (or lack thereof) toward achieving those sustainability goals;
- Diagnose obstacles to further progress and design opportunities for overcoming those obstacles;
- Build capacity for turning those diagnoses into programs of action in pursuit of sustainability.

Why we developed this course:

The idea of sustainability has a long history, accelerated but not initiated by the Brundtland Commission's publication of "Our Common Future" in 1987 and its follow up at the UN's Rio summit of 1992.[*] Early courses on the subject (including our own), tended to be either a smorgasbord of theories pulled from relevant disciplines and applied to selected problems, or single cases fleshed out with ad-hoc theories, or method-heavy hammers applied in search of sustainability nails. Over the intervening years, however, sustainability scholars across a wide range of research programs and disciplinary backgrounds have collaborated to develop approaches to teaching about sustainable development that more effectively integrate theory, cases, methods and practical experience.

This course emerged from our collaboration over many years in designing, teaching, and re-designing several courses in sustainability science and sustainable development for college students, graduate students, researchers, and practitioners.[†] Our approach begins with the fundamental recognition that any effort to foster sustainability necessarily takes place within a complex and co-evolving nature-society system in which shocks and surprise are the name of the game. It reflects our conviction that successful efforts to meet sustainability challenges must always be fit to place, sensitive to natural and social contexts, adaptive in the face of the unexpected, and humble in recognition of the complexity of the nature-society system. The course is shaped by our belief that efforts aiming to help students think analytically about the goals of sustainability and how better to pursue them in practice must complement thinking with doing – moving from simply asserting the problem, the complexity and the need to take local context seriously toward also devising actions and the means for implementing and learning from them.

To do this, this course focuses not just on immediate crises but on long-term development pathways of different peoples, sectors, and places around the world. Exploring long-term, large-scale patterns in

[*] World Commission on Environment and Development. (1987). *Our Common Future*. United Nations. http://www.un-documents.net/wced-ocf.htmCaradonna, J. L. (2014). *Sustainability: A History*. Oxford University Press.

[†] The approach we sketch here has been highly informed by our collaborations with colleagues including Arun Agrawal, Krister Andersson, Jeannine Cavender-Bares, Danny Bicknell, Ruth Defries, Christian Binz, Partha Dasgupta, Sam Elghanayan, Melissa Fiffer, Wyatt Hurt, Ann Kinzig, Lennart Kuntze, Michele Lamont, Eloi Laurent, Pamala Matson, Kira Matus, Julia Mason, Suerie Moon, Charles Perrings, Steve Polasky, Kevin Rowe, Oswaldo Sala, Afreen Siddiqi, Michaela Thompson, Bill Turner and generations of students. We are extremely grateful to all of these collaborators and many more not listed here for improving the way we have learned to teach this complex and important material.

development in the midst of today's multiple interacting crises may seem insensitive or irrelevant. It's not. History shows that transforming unsustainable development pathways onto more sustainable ones is the work of decades and must reach across countries and continents. Over such spans, surprises, shocks and crises are inevitable. These often cause horrific suffering and death. But they also disrupt the technologies, institutions and power alignments that stabilize the status quo. Crises thus provide rare opportunities for would-be change-makers to actually make a difference. Our explorations in this course seek to help individuals, communities, firms, or governments learn how to seize the opportunities of our present crises to bend the curve of development toward sustainability.

How this course is structured:

As we taught sustainable development courses over many years, we learned that combining generalizable theory with specific, placed-based studies of sustainability in action was more effective than relying on either approach alone. We therefore found ourselves developing both conceptual frameworks for analyzing sustainability and a set of concrete case studies to which we and our students apply the frameworks in explorations of how specific contexts shape sustainability challenges and solutions. Below we outline the current design of the course, providing an overview of how we utilize the frameworks and cases to help students integrate generalizable theory with sensitivity to specific contexts.

Part I: Sustainable Development as a Conceptual Challenge

The first step in our course is to develop a common understanding of the goals of sustainable development. Many different formulations of those goals have been set forth, ranging from the articulation in 1987 by the World Commission on Environment and Development (the "Brundtland Commission") of sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," to the three-pronged approach of balancing economy, society, and environment used by many textbooks, to the UN's more recent articulation of its "Sustainable Development Goals" (SDGs). We find it most useful to follow those leading scholars and international organizations that have begun with the globally negotiated conceptualization of the Brundtland Commission but have expanded the Commission's narrow concept of "needs" to a more expansive one encompassing "well-being." The most general goal of sustainability thus becomes development for which, at a minimum, human well-being both within and across generations does not decline.‡ Consistent with international development goals more generally, the course puts special priority on improving the well-being of the poorest and most vulnerable communities alive today, while conserving the ability of future generations to define and pursue their own well-being. Scholars have come to call this sustainability goal the promotion of "inclusive human well-being." While this general conception of sustainable development is helpful, is leaves unanswered what aspects of "inclusive well-being" will be most important to people in different places and times. This, we believe, should be seen as a feature rather than a bug, stressing as it does the importance of emphasizing that communities around the world as well as in future generations must be able to define for themselves what constitutes the specific elements of the good life are most important to them and how exactly they want to go about pursuing them in their own places and times. The 'longue durée' of the case studies we explore in the course provides a vehicle for exploring this "feature" of our approach.

Our next step in the course is to consider the resources—both natural and anthropogenic (or human-made) —that make up the productive base on which both current and future generations must draw to achieve their goals of enhanced and inclusive well-being. Well-being ultimately requires access to flows of goods and services such as food, energy, housing and education. Both theory and experience suggest, however, that for measuring sustainable development over long times and large spaces it is generally easier to measure the stocks of resources that function as its determinants (i.e. the means of

‡ An early, concise and accessible treatment of this conceptualization of sustainability is provided by Solow, R. (1993). An almost practical step toward sustainability. *Resources Policy, 19*(3), 162–172. https://doi.org/10.1016/0301-4207(93)90001-4; A more expansive version is Dasgupta, P. (2004). *Human Well-Being and the Natural Environment* (1st paperback, with revised Appendix). Oxford University Press.; Among international organizations, examples include the UN Sustainable Development Goals focus on "well-being" in SDG #3 (United Nations. (2021). *THE 17 GOALS | Sustainable Development*. https://sdgs.un.org/goals), and the OECD's focus on measures of "well-being" in its efforts to move "Beyond GDP" in assessments of social progress (OECD. (n.d.). *Well-being and beyond GDP*. OECD. https://www.oecd.org/en/topics/well-being-and-beyond-gdp.html).

achieving it) than to measure the flows of goods and services that are consumed as constituents of its ultimate end. The course reviews what those resources are and how they have been changing in different places around the world. Part I concludes by arguing that a particularly useful working definition of sustainability is pathways of development in which the *"inclusive wealth" represented by accessible resource stocks does not decline*. Again, the case studies we have integrated into the course provide an opportunity for students to explore how this definition might be applied in a variety of different local contexts.

Part II: The Anthropocene as a Complex Adaptive System:

With the ends and means of sustainable development in hand, our course then moves on to explore what science can say about future pathways for the promotion of inclusive wealth in the Anthropocene. To aid in these explorations, we introduce frameworks that help students take seriously the complexity of the nature-society systems that link resources to well-being without getting lost in their details. These frameworks are not explanatory theories – indeed they don't predict anything at all! Rather, they offer checklists of elements (variables) and relationships (processes) that research has shown to be worth considering in understanding and intervening in nature-society systems in particular contexts.

Part II starts with the simple framework that views nature-society interactions as dynamical systems whose development pathways are shaped – often in counter-intuitive ways -- by multiple stocks, flows and feedbacks. We then expand this initial framework to encompass two additional features of those systems: their persistent heterogeneity (one place is not like another) and their continuing generation of novelty (via biological mutations, technological inventions, or new policies). Together, these result in what is technically a "complex adaptive system" (CAS), with dynamics that exhibit far from equilibrium behavior replete with nonlinearity, tipping points, hierarchical self-organization and path-dependence. We next extend the framework to include explicit consideration of the processes connecting heterogeneous elements of the system, including "horizontal" ones such as trans-boundary pollution or migration, and "vertical" ones through which micro- and macro-level processes interact with one another to reshape phenomena as different as impacts of climate change and the spread of innovations. Finally, we introduce actors into our framework, emphasizing their diversity (individuals, firms, states, etc.), their agency (ability to set goals and take action), the institutional settings in which they interact, and their power over one another. Our summary of Part II includes an elaborated version of our initial framework, its application in the exploration of several of our case studies, and an assessment of its strengths and limitations for harnessing science in the pursuit of sustainability.

Part III: Capacities Needed for Sustainable Development

In the 3rd part of the course, we turn our attention to the capacities necessary for the pursuit of sustainability. We argue that advocates for sustainable development should pay greater attention to building a set of strategic capacities that empower and enable individuals, communities and organizations to make strategic decisions, and to take deliberate and collective action in the pursuit of sustainability. By "capacity" we mean both the intention and the ability to accomplish a task or achieve an outcome or, more bluntly, "the ability to get stuff done". Why? Because failure to build, exercise, and improve capacity for the pursuit of sustainability has too often resulted in a "missing middle"—an inability to connect widespread agreement on the goals of sustainable development with the scientific understanding of the dynamics of intertwined nature-society systems that set the stage on which those goals must be pursued.

We focus on six strategic capacities that recent research and practice have shown to be essential for "getting stuff done" in the pursuit of sustainability: i) the capacity to promote equity; ii) the capacity to measure progress; iii) the capacity to adapt to shocks and surprises; iv) the capacity to govern cooperatively; v) the capacity to link knowledge with action for sustainable development; and vi) the capacity to transform unsustainable development pathways to sustainable ones. We explore what research in sustainability science can tell us about each of these capacities.

Part IV: Next Steps: How do leaders catalyze progress in the pursuit of sustainability

The final part of the course consists of a single unit that explores how leaders have built, maintained and utilized the capacities discussed in Part III to promote sustainable development at scale.

How we have taught the course

From the earliest iterations of this course we have integrated some provision for having students continually apply the theory they are learning to messy sustainability challenges of the real world. This initially involved having us assign the most interesting case examples we knew to illustrate each of the ideas introduced in the course, and having students write individual term papers analyzing a sustainability problem of their own choosing. But we found that this approach fell short in three ways.

First, it encouraged students to engage sustainability problems as individuals with necessarily bounded expertise, whereas most real-world engagements involve team work to encompass the multidisciplinary complexity of those problems. This was pretty straight forward to resolve: we (re)built more of the course discussions and assignments around work carried out in student teams.

The second shortfall was harder. Our initial approach failed to generate an understanding of particular sustainability challenges shared by all students that would facilitate rich classroom discussion over how the theory applied in particular contexts. This led us to the realization that -- unlike many other fields -- the young science of sustainability still lacks common "problems" or model case examples that all are familiar with and can thus be used without explicit elaboration as common platform for exploring frameworks, theories, and hypotheses. (That is, we lack the "perfect markets" that provide a common reference point for economists, the "fruit flies" that do the same for geneticists, the "prey-predator cycles" of ecologists, the "Vostok ice cores" for climatologists, the "French Revolution" for historians, "Paris" for urban planners, "Java" for anthropologists etc.). We ended up addressing this shortfall by following a long tradition at Harvard's (and other universities') professional schools: creating our own set of rich case studies for use by us and others teaching sustainable development.

To build those shared cases for the study of sustainable development we needed to decide what the canonical case would look like. Though trial and error, we found that good candidates would generally cover multi-generational time scales. They would also avoid the sorts of disciplinary blinders that imposed when messy sustainability problems are treated as essentially environmental problems or essentially economic problems. Instead, they we determined that good cases would foreground the co-evolutionary dynamics of nature and society in today's Anthropocene world, exploring both how changes in society impact nature and how changes in nature impact society. Finally, good cases would be framed in ways that encourage not just thinking by scholars but also actions that decision makers might take in pursuit of sustainability. In practice, this meant building most cases around particular places (e.g. a region, a firm) or sectors (e.g. energy or food).

Our current set of "teaching" cases builds on an initial collaborative effort of one of us (BC) with Pamela Matson and Krister Andersson to provide common reference points for the book *Pursuing Sustainability: A guide to the science and practice* (Princeton Univ. Press 2016).[§] For that book the authors wrote short cases focused on irrigation in Nepal, agriculture in Mexico's Yaqui Valley, the interplay of nature and society in the history of London, and depletion of the global ozone layer. We used those cases in our evolving course, but eventually found that we also needed some even richer and more elaborated ones. We and our collaborators therefore wrote an expanded version of the London case together with additional cases on the Alaska salmon fishery and on natural resource use in Appalachia.[**] Together these six "teaching" cases constitute our current stock of common contexts and problems that we help all of our students to learn about, and against which we ask them to evaluate the theory, methods and

[§] Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press.

[**] Thompson, M. (2021). *The Alaskan Salmon Fishery: Managing Resources in a Globalizing World*. Harvard University.Harley, A., & Wexner, H. (2022). The Struggle for Sustainable Development in Appalachia's Mineral Rich Mountains. *Sustainability Science Program Working Paper*, *2022*(1), 65.

frameworks that constitute our core analytical approaches to sustainability science. The cases are thus a pedagogical tool used to help students think about sustainable development within the context of messy, complex, dynamical systems. We generally assign these cases within the first few weeks of the semester. We then return to them throughout the course to allow our students, individually and in groups, to explore the theoretical ideas and concepts of our syllabus as they play out in the pragmatic setting of our cases.

A third shortfall of our initial approach was that it deprived our students of precisely the agency we were trying to help them develop as active participants in the pursuit of sustainability. That is, our initial cases were essentially vehicles for us to teach the students about sustainability rather than opportunities for them to craft their own strategies for promoting sustainable development. To remedy this, we explored several means of helping students to pick "your case" to which they would apply lessons they were learning from the course to create practical guidance on how sustainability could be better pursued in that particular open-ended case setting. In the most formal version of this approach, we as instructors picked promising open-ended cases in which people were actively trying to pursue sustainability, provided a guide on basic facts of the case to help anchor students' work, but then turned them loose in teams to explore the challenges and opportunities to promote sustainable development in those "your case" settings. (The application cases that we have developed for the course include China's Pearl River Delta, the Brazilian state of Acre, and the East African nation of Uganda). But others teaching a version of this or similar courses in the future can also prepare their own "your case" studies, guided by the instructors' and students' current interests.[††] Even more flexibly, student teams are encouraged to pick any "your case" that interests them and (at least in our course after some negotiation with the instructor) then return to that case to apply what they are learning throughout the course. In all of these variants of the "your case" stream, students work in teams, and frequently adopt special areas of expertise and responsibility within those teams. Throughout the course, teams have opportunities to use the general ideas that have been presented in class to shape their research into the specifics of their case, and to report the results to other members of the full course. This work on the "your cases" has been in our most recent installment of this course the foundation both for a final symposium presentation by each team and for a final course paper by each individual student, centered on the case but with the focus within it a matter of choice by the individual student in consultation with the instructors.

There are clearly other ways to engage students in the complementary perspectives of theory and practice, of learning and of doing. But we have found the approach presented here to be the richest and most rewarding way we have yet come up with to help students learn about understanding and promoting sustainable development. The cases not only help students understand the sustainability challenges faced by different societies around the world, but also provide a foundation on which to develop both the analytical perspectives and the humility needed to begin fostering sustainability in the settings where the students themselves live and work.

[††] We provide in the Course Library a copy of our Uganda case to suggest how instructors might fashion background materials for their own "your case" selections: Harley, A. G. (2021). *Uganda Reading Guide for a course in sustainable development* (p. 17). Harvard University.

Unit 0.1 The challenge of sustainable development: How can human well-being be improved without degrading the planet's life support systems?

The growing concern for making development sustainable has been a response to tensions implicit in two global trends: rapidly increasing human well-being and rapidly increasing environmental degradation. These two trends, taken together, have come to be the perplexing and alarming characterization of what many are now calling the Anthropocene epoch of the planet's history.

The first of these global trends is described by Angus Deaton (see reading 'c') as "the great escape." It consists of the unprecedented improvements in human well-being that began in the late nineteenth century and accelerated especially in the second half of the twentieth century. By the early twenty-first century more than 80% of the people on Earth had life expectancies higher than those of people in the richest parts of the world as recently as 1950. And the fraction of the world's population living in absolute poverty was lower than it had ever been. This great escape has clearly left some people and regions behind, resulting in substantial and widening inequalities. And as indicated by the consequences of the covid pandemic and other recent disasters, continued success of the "great escape" is not guaranteed. By almost any metric, however, human well-being on Earth has never been higher for more people than it is today.

But this human progress has come with substantial environmental costs. These are reflected in the second major trend characterizing Anthropocene, described by John McNeill (see reading 'd') as "the great acceleration." It encompasses the increasing magnitude and global extent of human impacts on nature. By the dawn of the twenty-first century, no corner of the Earth's environment had escaped transformation by human activities. The great acceleration had certainly entailed significant cases of environmental protection and restoration. But its overall thrust showed few signs of abating, as reflected by increasing attention to the planet's great poisoning by toxic chemicals, the mass extinction of its biota, and above all its multifaceted climate crises.

It has been clear at least since the 1987 report of the Brundtland Commission that the "great escape" from poverty toward equitable improvements in human well-being cannot be sustained in a world that continues to be characterized by its current "great acceleration" in environmental damages. The problem addressed by this course is to understand the long-term, interacting trends of development and environment shaping the Anthropocene: what drives them, how they interact in particular places and sectors, and how they can be transformed in the pursuit of sustainability (see Matson et al. reading 'a').

Preparation for class: To prepare for the class, please:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Ch. 1, "Pursuing sustainability: An introduction" (pp. 1–13).
This book provides the central text for the course, and we will return to it frequently. It is available from most online book sellers and as a (cheaper) e-book from the usual online sources. A free copy of the first chapter, assigned for this class, is available here from Princeton University Press. Note that the four case studies of the pursuit of sustainability introduced in this reading are presented in greater detail in Appendix A of the book.

b) **Watch**: Steiner, A. (Director). (2020, December). *Humanity's planet-shaping powers—And what they mean for the future | TED Talk*. United Nations Development Program. (19 min.) Link here.

c) **Read**: Deaton, A. (2013). *The Great Escape: Health, Wealth, and the Origins of Inequality*. Princeton University Press. Read Chapter 1: "The wellbeing of the world" (pp. 23-56).

d) **Read**: McNeill, J. R. (with Engelke, P.). (2016). *The Great Acceleration: An Environmental History of the Anthropocene Since 1945*. Belknap Press of Harvard University Press. Read "Introduction" (pp. 1-6) and "Conclusion" (pp. 207-211).

e) **Explore**: Roser, M. (2024). *Our world in data*. https://ourworldindata.org/ .
This is an excellent web site with up-to-date trends and analysis. Pick a couple of the environmental trends and a couple of the social trends mentioned in the other readings for this unit and explore them on the "Our World..." web site (see study question I and II.).

Study Questions to help you get the most out of the readings:

I. **Across generations:** Sustainable development is a multigenerational challenge, concerned with what one generation hands on to the next. Using the "Our World in Data" site (see reading 'e'), compare the state of the world today with its state where and when you, your parents, and your grandparents were born. In particular, as indicators of well-being, compare life expectancy at birth, child mortality rates, and any other property that particularly interests you. As indicators of the environment, compare land use, air pollution rates, and any other property that particularly interests you. Which generations have seen the greatest changes in which aspects of their well-being and environment? The least?

II. **Across regions:** Sustainable development is a global challenge, concerned with how different places around the world compare and interact with one another. Pick a world region that interests you but is different from the one in which you grew up. Using the same "Our World in Data" indicators you explored in (I), compare the multigenerational development pathways of that region and the region in which you grew up. For which of the indicators you considered are the regional differences largest? Smallest?

III. **Across contexts**: The multigenerational, global challenge of sustainable development takes on different faces in different contexts. How would you characterize the similarities and differences in the sustainability challenge faced by actors in the 4 case studies introduced in the Matson et al. reading?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

f) **Read** further in Deaton, A. (2013). *The Great Escape: Health, Wealth, and the Origins of Inequality*. Princeton University Press.

g) **Read** further in McNeill, J. R. (with Engelke, P.). (2016). *The Great Acceleration: An Environmental History of the Anthropocene Since 1945*. Belknap Press of Harvard University Press.

Unit 0.2 Tragedies of the Commons: Why is sustainable development so hard?

Managing the dynamics of nature-society interactions for sustainable development is really hard! Nonetheless: 1) It must be done, and 2) We can learn to do it better. Trying out new approaches on simulated nature-society systems is safer and can be more informative than using the real world as a guinea pig. Simulations play a central role in modern research and policy design for sustainable development, and will appear frequently in the readings for this course where we will use them to address questions of public health, climate change, energy systems, biodiversity conservation, etc. We begin our pursuit of sustainability in this class with one such simulation: managing the commons of an open-access ocean fishery. Your goal at the most general level will be the same as for many sustainability efforts: to improve well-being of people now while limiting environmental degradation, and to do so in a way that passes on to the people of the "next generation" a world that gives them at least as good an opportunity to thrive as did the one they inherited from their parents. In the particular case of this fisheries simulation, your goal will be to improve the wealth of fisher* communities while limiting depletion of fish stocks, and to end the game with a combination of fish and fisher prosperity that has at least as much potential for future development as you had when the game began.

This Unit is devoted entirely to playing a simulation game called "Fishbanks" and reflecting on the results of that play. Fishbanks was developed by Prof. John Sterman and his colleagues at MIT, who have posted it online as a public good (see Readings below). The simulation can involve an indefinite number of participants and can be conducted either virtually or in the classroom. Students play the role of fishers, while the course instructor runs the game and serves as referee. The game has sufficiently many moving parts that careful study the readings listed below is essential for success.

We will come back to the Fishbanks case, and your explorations of it, frequently throughout the course.

Preparation for class To prepare for the class, please:

a) **Read**: Meadows, D., Sterman, J., & King, A. (2024). *Fishbanks: A Renewable Resource Management Simulation*. https://mitsloan.mit.edu/teaching-resources-library/fishbanks-a-renewable-resource-management-simulation.
This is the home page for the Fishbanks simulation from which you will play the game solo as homework and as a team in class. It is also where you can access reading 'b' below.

b) **Watch**: Sterman, J. (Director). (2011). *Fishbanks: A renewable resource management simulation: A video introduction* [Video recording]. MIT Management Sloan School. https://forio.com/simulate/mit/fishbanks/simulation/login.html.
This video runs about 36 minutes. It provides essential background to how you will play your role in the class simulation. It can be accessed through the main link provided above to the Fishbanks simulation. Scroll down and click on "Play Simulation" and then on the page that opens, look on the right-hand side for the Student menu click "View instructional video".

c) **Read**: Sterman, J., & King, A. (2011). *Introduction to Fishbanks* (Nos. 11–133; p. 2). MIT Sloan Management. https://forio.com/simulate/mit/fishbanks/simulation/downloads/english/Fishbanks%20Introduction.pdf
This is a two-page summary of essential preparation for the in-class gaming session including the decisions you will need to make in each round of the simulation.

d) **Play**: Please play the Fishbanks simulation solo before class to get the feel of the game. See additional details about how to do this here: *Fishbank preparation for Students* (in) Course Library. Then play the Fishbanks simulation as part of a class. (Note: Before you can play as a class, an

* We use the term "fisher" to include all people involved in fishing.

instructor (or other leader for your class) will have to do some set up, and then run the game. Instructions for the instructor(s) is here: *Fishbank preparation for Instructors* (in) Course Library.

Study Questions to help you get the most out of the readings:

I. **Some questions to consider after playing your solo game(s):**
- What was your worst mistake in your role as a solo fishing fleet?
- What indicator(s) available for reporting on the state of the fishery were most useful for managing it? Why?
- What additional indicator would you have most liked to have? Why?
- How would you describe to a novice fisher your strategy for sustainable development of the fishery from your perspective as the only fleet in the ocean?

II. **Some questions to consider in strategizing for the multi-player in-class game:**
- Relative to your "solo" experience with Fishbanks playing as the only fleet in the ocean, how do you expect the presence of other fishing fleets in the multi-player simulation to change the likely outcome of the game? To change the challenges of devising a good strategy?
- What should be your team's goal for this multi-fleet game? How will you measure progress toward that goal during the game? Why?
- What should be your team's strategy for managing its own fleet in this multi-team version of the game? How will this change from when you played it as an individual? What knowledge from the previous iteration might you incorporate into your approach this time, and why?
- Do you believe that pursuing collaborative strategies with other teams is a useful approach? Why or why not? What strategies might you pursue, and why? What is your plan for revising your strategy if it doesn't work?

III. **Some questions for class discussion after playing the multi-player game:**
- How did the classroom community of fishers do in managing the fishery?
- Why is it so hard to develop the Fishbanks fishery sustainably?
- How might the classroom community of fishers do better next time?
- What can this experience teach us about the challenges of managing fisheries for sustainability? Of managing for sustainability more generally?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

The next three readings provide insights into recent progress and remaining challenges in managing fisheries for sustainability:

h) **Read**: Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., Fogarty, M. J., Fulton, E. A., Hutchings, J. A., Jennings, S., Jensen, O. P., Lotze, H. K., Mace, P. M., McClanahan, T. R., Palumbi, S. R., Parma, A. M., Rikard, D., Rosenberg, A. A., Zeller, D., & Minto, C. (2009). Rebuilding Global Fisheries. *Science*, *325*(5940), 578–585. https://doi.org/10.1016/j.marpol.2017.02.003

i) **Read**: Hilborn, R., & Costello, C. (2018). The potential for blue growth in marine fish yield, profit and abundance of fish in the ocean. *Marine Policy*, *87*, 350–355. https://doi.org/10.1016/j.marpol.2017.02.003.

j) **Read**: Roberts, C., Béné, C., Bennett, N., Boon, J. S., Cheung, W. W. L., Cury, P., Defeo, O., De Jong Cleyndert, G., Froese, R., Gascuel, D., Golden, C. D., Hawkins, J., Hobday, A. J., Jacquet, J., Kemp, P., Lam, M. E., Le Manach, F., Meeuwig, J. J., Micheli, F., … O'Leary, B. C. (2024). Rethinking sustainability of marine fisheries for a fast-changing planet. *Npj Ocean Sustainability*, *3*(1), 41. https://doi.org/10.1038/s44183-024-00078-2.

Unit 1.1 A Framework for Sustainability Analysis: How can we harness science to understand the complexities of the Anthropocene System?

The variety of complex interactions between human development and the natural environment make it difficult to identify actions that support the pursuit of sustainability. A growing body of scientific research, however, can help.

Part I of this course develops a simple framework you can use for harnessing that research for sustainability analysis. This Unit provides an overview of that framework. Subsequent units expand on it by introducing additional elements and relationships that science has shown to be important in understanding social-environmental systems[i] and shaping decisions in pursuit of sustainability.

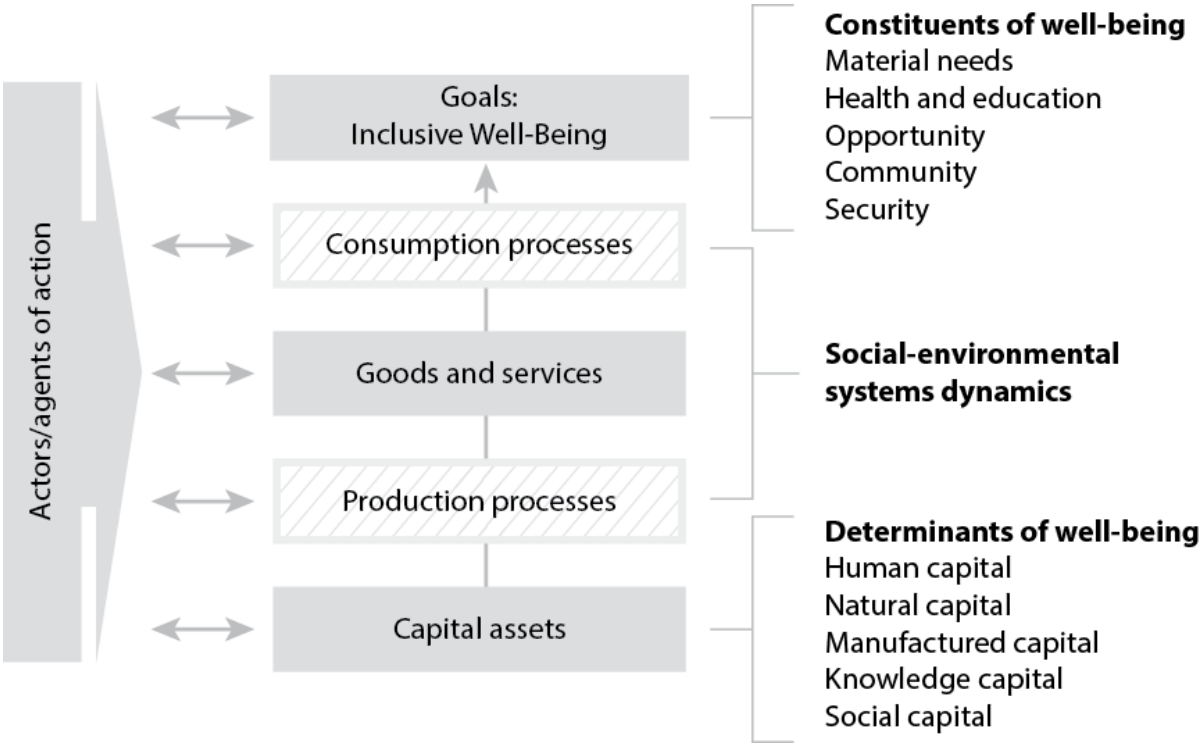

Figure 1: Matson et al. 2016

The framework presented in the readings (and reproduced in figure 1 above) provides a way to analyze sustainability challenges. At the top, it shows human well-being—the ultimate goal of sustainable development. On the bottom, it shows the resources that serve as capital on which people can draw to reach their goals. Connecting these are the social-environmental (nature-society)* systems that shape the dynamics of planet earth. The framework emphasizes the processes of production and consumption that, within the overall social-environmental system, are the focus of most human interventions. Those interventions are taken by actors: individuals, firms, communities, states. As you'll see in the readings, understanding these relationships is key to identifying interventions that can advance sustainability.

A cautionary note: The field of sustainability science is rapidly advancing, drawing on findings in multiple disciplines. This means that the frameworks we present here are far from the only ones being used

* Note that in the more recent literature, an equivalent term to the one used in the figure has been introduced: the nature-society system. We will use this more recent terminology going forward, but both mean the same thing— the integrated systems formed by the co-evolution of human societies and the natural environment.

around the world – they're just the ones we have found to be most inclusive and useful. And even "our" frameworks are in flux, with the early version set forth in the Matson et al. book (see reading 'a') extended substantially in the more recent versions we introduce in Part II. Future research and experience will doubtless lead to additional refinements and improvements.

Preparation for class: To prepare for the class, please:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Read "A framework for sustainability analysis…" (pp. 14-20, top of page).

This reading provides a concise summary of the early version of the framework we use in this course (reproduced above). It is important to read carefully because it introduces some of the most important ideas and terminology that the authors used throughout the book and that we adopt in later Units.

b) **Read**: Thompson, M. (2021). *The Alaskan Salmon Fishery: Managing Resources in a Globalizing World*. Harvard University. (in) Course Library pp. 1-25.

Study Questions to help you get the most out of the readings:

I. **Nature-society interactions:** The framework presented in figure 1 and detailed in reading 'a' shows the social-environmental (aka nature-society) system on the right side. For the Alaska salmon fishery, identify the main components of this system (both natural and social) and sketch how they interact. What are the key two-way relationships between salmon ecosystems and human communities?

II. **Goals:** What are the most intensely felt goals held by various groups in the Alaska salmon fishery? Consider fishers, processors, Native communities, conservationists, and the state government. How do these goals align and where do they conflict?

III. **Resources:** The framework highlights "capital assets" (also referred to as natural and anthropogenic resources in this course) as the ultimate source of human well-being. What capital assets (natural, human, manufactured, social and knowledge) are most important to changes human well-being that occur in the course of the Alaska case?

IV. **Consumption-production system:** The framework highlights the consumption and production processes through which people harness the resources of the nature-society [social-environmental] system to achieve their goals for a good life. In Fishbanks, what is the relevant consumption demand and how is it set? What are the key production processes? How are consumption and production processes related? Think through the same questions for the Alaska fishery case. What seems to drive changes in salmon abundance from year-to-year and how do humans respond?

V. **Preliminary sustainability assessment:** From this first look at the Alaska fishery case, what do you see as its prospects for sustainable development? What aspects of the system are enhancing those prospects? What aspects raise concerns? (Note: You'll revisit this question with increasing sophistication in Units 1.5 and 2.7 as you develop more analytical tools).

Unit 1.2 Goals for Sustainable Development: What kind of world do people want?

Sustainable development, if it is to have meaning, must be about the development of *something*. As individuals, we are free to insist that words mean whatever we want them to. But if we want to communicate with—much less cooperate with—others, then shared meanings captured in shared goals are essential. In this class we draw from sustainability scholarship to advance and critique the following propositions about goals for sustainable development:

- The "something" that *sustainable* development should be about is people's well-being, not more traditional objectives such as an economies' GNP or a nations' security;
- The strong normative commitment of sustainable development to intra- and inter-generational equity means that its goal should be about *social* well-being, i.e. should address the fair distribution of well-being across people in multiple places and times;
- The particular constituents of well-being that matter most to different people and groups vary across circumstances, times and places, raising challenges for articulating common goals;
- An essential step toward crafting shared goals in all public policy is to distinguish between the ultimate ends that policy is meant to achieve and the multiple means that may turn out to be useful or even necessary for achieving those ends. For sustainable development, this requires distinguishing between its ultimate goal or end (that we have argued is "equitable improvements in social well-being") and the multiple actions or means that different groups advocate to achieve that end.

Preparation for class:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. "Conceptualizing well-being" (pp. 20-23) and "Constituents of well-being" (pp. 23-32).

This reading summarizes the argument for framing the overarching goal for sustainable development in terms of social well-being and its equitable distribution within and across generations. The reading focuses on the *constituents* of social well-being – the multiple dimensions on which people characterize what's most important for their sense of well-being.

b) **Read and explore:** OECD. (n.d.). *OECD Better Life Index*. Retrieved July 1, 2024, from https://www.oecdbetterlifeindex.org/.

How do different people around the world characterize what well-being is for them? The Organization for Economic Co-operation and Development (OECD) has led the way in survey work to provide "bottom-up" answers to this question, grounded in the views of individuals (mostly, it must be said, from the richer parts of the world). This interactive web site provides an entry point to the methods and results of their work. You can use it to explore the constituents of well-being most important to you, and to see how your views about important constituents and their distribution compare with those of other people in other places.

c) **Read**: United Nations. (2021). *THE 17 GOALS | Sustainable Development*. https://sdgs.un.org/goals

A focus on social well-being is not the only way to view the kind of world people want. The United Nations' Sustainable Development Goals (SDGs) constitute the global community's most elaborated answer yet to the question of what sustainability should be about. The SDGs emerged from the UN Sustainable Development Summit of September 2015 as the outcome of a multiyear process in which nations, civil society groups, businesses and others negotiated what kind of world they wanted for 2030 and outlined an action agenda for reaching them. The resulting "top down" list of targets is messy (as are the results of most political negotiations) but also reflects a broad and deep consensus of international opinion leaders of a sort rarely seen. To get a sense of that consensus please review this high-level UN website.

Study Questions to help you get the most out of the readings:

I. **Characterizing your own well-being and comparing others people's "bottom up" perspectives**: Use the "Better Life Index" of the OECD assigned in reading 'b' for this unit to explore a "bottom up" view of how people see the constituents of a "better life". Guidance on how to use the index effectively is provide in the Course Library document "OECDs Better Life Index: How to use it for the Sustainable Development course." In particular, address the following questions:
- Which of well-being constituents identified by OECD are most important to you? Which seem to be describing the ultimate end of a "better life?" Which are better seen as means for achieving well-being? Which other items would you add to OECD's list in order to have it better capture the constituents of well-being that you would be comfortable using to define your goal for sustainable development?
- Which are the places (of those indexed by OECD) where your vision of the good life is most likely to be realized? Least likely to be realized?
- Compare the rankings of constituents in the two countries you identified in the preceding question. What constituents of well-being are most responsible for the differences between the two?

II. **Understanding the UN's "top down" effort to design its SDGs**: Explore the UN SDG web site assigned as reading 'c' for this unit.
- Begin by reviewing the "History" section halfway down the home page. How did the UN SDGs come to be? Whose voices counted in articulating them? Whose were excluded?
- Next, scroll over each of the 17 SDGs listed at the top of the page to get an idea of what they are about. Pick one or two of the 17 that most interests you and drill down on the relevant tabs to get a sense of the argument, activities and metrics behind it.
- Which of the SDGs identified by the UN seem most important to you? Why? Which seem to be describing the ultimate ends of sustainable development? Which are better seen as means for achieving sustainable development? Which other items would you add to UN's list in order to have it better capture the what you believe should be the world's goals for sustainable development?

III. **Equity in goals for sustainable development**: In the canonical framing by the World Commission on Environment and Development (the Brundtland Commission), sustainable development must "meet the needs of the present without compromising the ability of future generations to meet their own needs," thus underscoring the importance of inter-generational equity. Later deliberations made explicit concern – present but implicit in the Brundtland formulation -- for intra-generational equity, i.e. that advances in development for some should not come at the expense of development for others. But characterizing equity is tricky. For practice:
- Return to the "Our World in Data" segment on changing life expectancy across generations and places that you explored in Unit 0.1 reading 'e' on the "Challenge of Sustainable Development." How do the data presented there support the author's conclusion that "The world developed from equally poor health in 1800 to great inequality in 1950 and back to more equality today – but equality on a much higher level."[*] Does his stated conclusion miss anything important about equity apparent in the data?
- How does the OECD "Better Life…" effort treat equity? (You may find it useful to start here: https://www.oecdbetterlifeindex.org/about/better-life-initiative/#question11). For use in the pursuit of sustainability, what are the strengths and weaknesses of the OECD treatment of equity?
- How does the UN SDG effort treat equity? (SDG #13 explicitly focuses on some aspects of equity. Dig deeper to see how equity is (or isn't) treated in the other SDGs). For use in the pursuit of sustainability, what are the strengths and weaknesses of the UN SDG treatment of equity?
- Would you be OK with a development pathway that resulted in continued increases of inequality but also alleviated the worst depredations of poverty? How about a pathway that involved radical reductions in the consumption that supplies our well-being today in order to assure that future

[*] Max Roser (2015) - "Life expectancy increased in all countries of the world" Published online at OurWorldinData.org. Retrieved from: 'https://ourworldindata.org/life-expectancy-increased-in-all-countries-of-the-world' [Online Resource]

generations still have sufficient resources to pursue their own well-being? How would these pathways "score" on the OECD and UN treatments of sustainability goals? Why?

IV. **Negotiating common goals**: Finally, imagine that you need to negotiate a goal of sustainable development that most players on the global stage would endorse as a focus for cooperation. What would you come up with? What would your approach take from the "bottom up" OECD approach and the "top down" UN approach. Why?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

d) van Zanden, J. (2014). *How Was Life?: Global Well-being since 1820* (p. 273). OECD. https://www.oecd.org/statistics/how-was-life-9789264214262-en.htm
A continuation of the OECD project cited in reading 'b', but looking at how visions of the good life have changed through time.

e) Lintsen, H., Veraart, F., Smits, J.-P., & Grin, J. (2018). *Well-being, Sustainability and Social Development: The Netherlands 1850-2050*. Springer International Publishing. https://doi.org/10.1007/978-3-319-76696-6
A multidisciplinary investigation of how contemporary peoples' views of the good life are changing over the century time scales relevant to sustainability. (Note: We hope it is easier to read for those fluent in the original Dutch).

f) Kamau, M. (with Chasek, P. S., & O'Connor, D. C.). (2018). *Transforming multilateral diplomacy: The inside story of the Sustainable Development Goals*. Routledge, Taylor & Francis Group.
An insider's account of the political negotiations behind the UN SDGs, revealing how diverse nations, despite different visions of well-being and sustainability, negotiated the messy compromises needed to create shared global goals.

g) Taylor, C. (2024). *Cosmic Connections: Poetry in the Age of Disenchantment* (1st ed.). Harvard University Press.
Most accounts of well-being or the good life acknowledge that some people (and perhaps humanity more broadly) may include among the constituents important to them not only material ones such as access to housing and water but also more spiritual or subjective ones such as the feeling that one is connected with nature. This work explores how peoples' experience of such connectedness was gradually lost through the rise of instrumentalist views through impact of the Enlightenment, and how artists of the Romantic era sought to reconnect people and nature. The book can be tough going, but the reward is a final chapter in large part devoted to the writings of Annie Dillard (e.g. her *Pilgrim at Tinker Creek* (1998). Harper Perennial).

Unit 1.3 Resources for sustainable development I: How do natural resources shape the prospects for sustainable development?

The ultimate determinants of humanity's ability to achieve sustainability goals are the *stocks of resources* afforded us by the global nature-society system. The central argument is that the current stock of resources constitutes the "fuel in the tank" or "capital assets" on which each generation can draw to generate a flow of goods and services it can consume in pursuit of its own goals of well-being. The amount of resource or asset stocks we have on hand, like the fuel we might have in our gas tank, thus partially determines our future options. The sustainability question then becomes one of whether each generation is managing the depletions of, and additions to, its stock of resources in such a way that it can hand on an aggregate stock to its successors that is of at least equal value for supporting inclusive well-being as was the stock that generation inherited from its parents.

The particular resource stocks most relevant to sustainability can conveniently be divided into two groups, those provided by nature (natural resources) and those provided by people (anthropogenic resources). The pursuit of sustainability can involve both depletion of and investment in these resources, as well as tradeoffs that enhance one group of resources by depleting others. (Terminology note: Much of the literature follows the economists in referring to "capital" and "assets" rather than to "resources." The more general term we have come to prefer is "resources." But in the context of sustainability analysis, all of these terms can be taken to mean the same thing).

This Unit begins our discussion of the determinants of sustainable development by focusing on the natural resources of:

- Foundations: Land and water
- Materials: Hydrocarbons (including fossil fuels), metals, and other minerals.
- Life: Biomass and biodiversity

Natural resources constitute the primordial determinants of human well-being. A general overview of natural resources, the flow of goods and services they contribute to well-being, and their patterns across space and time is provided in the readings. One note of caution: It turns out to be important to distinguish between the *stocks* of natural resources (e.g., hectares of forest, numbers of fish, reserves of lithium, amount of fresh water) and the *flows* of goods and services that people extract from those stocks to achieve well-being and other goals (e.g., harvest rates from the forest or fishery, consumption of water, rates of mining, etc.). We will discuss why this distinction is important in unit 2.1 on system dynamics.

Preparation for class:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Review pp. 14-20, Read "The determinants of well-being… Natural capital (pp. 32-37); and "Farmer-managed Irrigation Systems in Nepal" (pp. 163-172).

An introduction to resources (here called "assets") as the determinants of well-being, and an overview of some of the natural resources most relevant to the pursuit of sustainability. And a fuller version of the Nepal case introduced in Unit 0.1.

b) **Read**: United Nations Environment Programme. (2024). *Global Resources Outlook 2024: Bend the Trend – Pathways to a liveable planet as resource use spikes*. International Resource Panel. https://www.resourcepanel.org/reports/global-resources-outlook-2024. The "Summary for Policy Makers" of this massive report can be accessed from the main page listed here. In that Summary, read for this unit pp. 9-18. (We draw on the Summary's prescriptions for action, pp. 19-29, later in the course).

This work summarizes the role of natural resources (land, water and materials) in sustainable development: how they contribute to "provisioning" the food, built environment, mobility and energy that shape social well-being, trends in how their stocks are changing as a result of human use, and

what the prospects are for bending those trends in the pursuit of sustainability. (The unfortunate title – which implies that all resources relevant to sustainability are from nature – is symptomatic of the disciplinary silos that still plague sustainability studies. The next unit addresses the complementary anthropogenic resources missing here).

Study Questions to help you get the most out of the readings:

I. Efforts to provision the constituents of well-being draw on many natural resources. For example, meeting needs for consumption of food involves agricultural production processes that draw on multiple natural resources including (at least) land, water, energy, and biodiversity. Consider another constituent of well-being identified in your work with the OECD "Better Life" effort (Unit 1.2): "housing." Which natural resources are most needed to provide the housing you have recently used? Think back to the housing of your grandparents generation: How did the resource demands needed for provisioning their housing differ from those of today?

II. What are the stocks of natural resources that played central roles in the Fishbanks game? In the Nepal and case from the Matson et al. book? What are the flows from those stocks that affect the servicing or provisioning of key constituents of well-being for people in the Nepal case?

III. In the London case from the Matson et al. book, lots of natural resources were required to rebuild the city in the wake of the multiple calamities it faced through the ages. What were the most important of those natural resources? Were they "materials" or "foundational land and water" or "living resources"? Where did they come from? Was the sourcing of those resources by London consistent with the "equity" dimensions of sustainable development goals?

IV. The claim is often made that increasing scarcity of natural resources will result in higher prices for them, which will automatically decrease demand and increase the search for alternatives. For which resources, and which conditions, is this a reasonable claim? For which not? Why?

V. **Your case**: Consider the sustainability challenge you're following throughout this course. First, identify three important natural resources for your case (they could be foundational, materials, or life resources). Second, for one of these resources, describe both what exists (the stock) and what's being used or extracted (the flow). Third, write about what concerns you (if anything) about this resource's future availability?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

c) Read: Dasgupta, P. (2021). *The economics of biodiversity: The Dasgupta Review*. https://royalsociety.org/news-resources/projects/biodiversity/economics-biodiversity/.

Ecosystems are the natural resource addressed in this introduction to an independent, global review commissioned by the UK Treasury in 2019. The author is Partha Dasgupta, one the world's leading scholars of sustainability. The Review's focus, despite its name, is on the "life" dimensions of natural resources, i.e. on ecosystems and biodiversity and how these can contribute to sustainable development.

d) Read: Chaplin-Kramer, R., Neugarten, R. A., Sharp, R. P., Collins, P. M., Polasky, S., Hole, D., Schuster, R., Strimas-Mackey, M., Mulligan, M., Brandon, C., Diaz, S., Fluet-Chouinard, E., Gorenflo, L. J., Johnson, J. A., Kennedy, C. M., Keys, P. W., Longley-Wood, K., McIntyre, P. B., Noon, M., … Watson, R. A. (2023). Mapping the planet's critical natural assets. *Nature Ecology & Evolution*, *7*(1), 51–61. https://doi.org/10.1038/s41559-022-01934-5.

Ecosystems are the focus of this research that uses the framework introduced by Matson et al. (reading 'a') and by Dasgupta (reading 'c') to map the locations of ecosystems that contribute most and most directly to human well-being. The authors use the maps to propose action priorities for ecosystem conservation. Their terminology, however, does not quite match ours so here is a guide: For the "Goals" of sustainable development, these authors take (as we do) human well-being; the

authors address “critical natural assets (resources)”, but cover only ecosystems, not materials; for the “Goods and Services” of the Matson et al. framework, these authors focus on a dozen of “nature’s contributions to people (NCPs)” that have been identified in the recent assessments as being produced from ecosystems.

Unit 1.4 Resources for sustainable development II: How do anthropogenic resources shape the prospects for sustainable development?

The resources directly provided by nature that we discussed in the previous Unit are essential determinants of people's well-being. But through the course of human development, people have used those natural resources to construct additional resources that are now complementary sources of the goods and services used by people to foster well-being. These "anthropogenic" resources have been the focus of much work on the development of economies and are thus often referred to as "assets" or "capital assets." For the purposes of sustainability analysis, they may be conveniently grouped as:

- **Human capital**: people – their health, education, and numbers;
- **Manufactured capital** (also called "produced capital"): human-made systems of roads, buildings, ports, machinery, telecom hardware, pharmaceuticals and personal "stuff";
- **Social capital**: trust, norms, and institutions;
- **Knowledge capital**: understanding of how the world is that is codified in books, journals and patents as well as experiential and indigenous knowledge that is widely shared among people (whether written down or passed on orally).

Each of these anthropogenic resources can contribute directly to society's well-being. They also frequently serve to enhance the benefits that society draws from its stock of natural resources (consider the workings of the plow or the internal combustion engine) and human capital (consider the transportation or information infrastructures that help us get our skills to where they will be most useful). The dynamics and contributions of anthropogenic resources to well-being clearly depend on how they are interconnected with one another. Other things being held constant, investment in many kinds of anthropogenic resources should increase the size of a society's resource base and thus its potential to support increased and inclusive well-being. The challenge for the pursuit of *sustainable* development is that "other things" are not constant. In particular, the creation and use of particular anthropogenic resources, while providing many benefits to society, can be accompanied by damage to the natural resource base and thus may constitute a net loss in the social value of the total bundle of resources available. For example, the environmental services provided by trees are lost when forests are cleared to build factories; people are poisoned by the wastes created in running those factories; synthetic chemicals that are useful to people for one thing also turn out to damage them. Growing the ability of the aggregate resource base to support sustainable development requires awareness and management of such trade-offs.

Preparation for class: In preparation for class, please:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press.
   - **Read**: Sections on anthropogenic resources (pp. 37-50,top of page),
   - **Read**: The case study "London: The struggle for sustainable development in an urban environment" (pp. 143-165).

b) **Read** the following brief overviews of the principle anthropogenic resources:
   - **Human capital:** Kurzgesagt – In a Nutshell (Producer). (2016). *Overpopulation – The Human Explosion Explained* [Video recording]. https://www.youtube.com/watch?v=QsBT5EQt348
   - **Manufactured capital**: Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H., & Haberl, H. (2017). Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proceedings of the National Academy of Sciences*, *114*(8), 1880–1885. https://doi.org/10.1073/pnas.1613773114
   - **Social capital**: Ortiz-Ospina, E., Roser, M., & Arriagada, P. (2024). Trust. *Our World in Data*. https://ourworldindata.org/trust

- **Knowledge capital**: Hess, C., & Ostrom, E. (2007). Introduction: An overview of the knowledge commons. In C. Hess & E. Ostrom (Eds.), *Understanding Knowledge as a Commons: From Theory to Practice* (pp. 3–26). MIT Press.

Study Questions to help you get the most out of the readings:

To provide focus, the study questions listed below refer to the London case study assigned in reading 'a'. You can also think about the same questions for any case you know a lot about.

I. **Human capital in London:** What are the trends in each component of human capital in the London case during each phase of London's history? How strongly would you weigh trends in individual dimensions of human capital for your overall assessment of London's inclusive human well-being? In other words, which of the observed trends in population, health, or education of people in London most strongly influenced overall human well-being in each phase of London's development? Were trends in other resources more important?

II. **Manufactured capital in London:** What are the stocks of manufactured capital that are most central to peoples' efforts to improve their well-being in the London case? What are the most important processes through which these stocks of manufactured capital increased or decreased over time? In what ways have efforts to increase the stock of manufactured capital in London damaged or improved the stock of natural capital or human capital there?

III. **Social capital in London:** What are the trends in social capital for the London case? What are the key kinds of social capital created during each phase of history that allowed people to collaborate on a problem that had previously inhibited the pursuit of well-being there? How did these forms of social capital contribute to inclusive well-being and sustainable development? There is much talk of a "dark side" of social capital. This often manifests as a product of inequity—powerful actors have the ability to shape the institutions (rules of the game) to further entrench their own power. What are the most important ways in which an increase in "dark" social capital may have undermined the prospects for sustainable development in the London case? In other cases you are familiar with?

IV. **Knowledge capital in London:** What are the most important trends in knowledge capital for the London case? What are some ways in which London's knowledge stock grew? Declined? Are there key examples of knowledge capital throughout the history of London that significantly contributed to net gains in human well-being in the city? What mechanisms added this valuable knowledge capital to the London system?

V. **Interacting resource stocks in London:** How did each of the natural and anthropogenic resource stocks we have studied in this and the previous Unit contribute to London's development pathway? To do this pick a specific time period in London's history you are interested in, then 1) List trends in each of the seven resource stocks in the time period you selected (if there is not enough data about a particular asset stock provided you can either do some research yourself or skip it; 2) Describe the ways in which changes in each of the resource stocks impacted other resource stocks and overall human well-being (those impacts can be both negative and positive).

VI. **Your case:** Think about anthropogenic resources in your own case. First, create a simple table showing the current status (growing, stable, declining) of each anthropogenic resource in your case. Second, identify an anthropogenic resource constraint limiting sustainable development in your case. What makes this resource particularly important? Third, analyze one key interaction between anthropogenic and natural resources in your case - is there a tradeoff where building one type of capital degrades another? Or a synergy where investments in one enhance another?

Digging deeper (optional materials for further exploring the anthropogenic capital that most interests you):

Human capital

c) Lundborg, P., Nordin, M., & Rooth, D. O. (2018). The intergenerational transmission of human capital: The role of skills and health. *Journal of Population Economics*, *31*(4), Article 4. https://doi.org/10.1007/s00148-018-0702-3

Especially important perspective on how what you get from your parents' generation shapes your prospects for well-being.

d) Jumbri, I. A., Ikeda, S., & Managi, S. (2018). Heterogeneous global health stock and growth: Quantitative evidence from 140 countries, 1990–2100. *Archives of Public Health*, *76*(1), 81. https://doi.org/10.1186/s13690-018-0327-8

Manufactured capital

e) Weisz, H., Suh, S., & Graedel, T. E. (2015). Industrial ecology: The role of manufactured capital in sustainability. *Proceedings of the National Academy of Sciences*, *112*(20), 6260–6264. https://doi.org/10.1073/pnas.1506532112 .

A survey of how the physical stuff that society produces does (and does not) affect its prospects for sustainable development

f) Södersten, C.-J., Wood, R., & Wiedmann, T. (2020). The capital load of global material footprints. *Resources, Conservation and Recycling*, *158*, 104811. https://doi.org/10.1016/j.resconrec.2020.104811 .

A valuable effort to link two approaches to accounting for the role of manufactured capital in sustainable development: asset stocks and material footprints.

g) Krausmann, F., Schandl, H., Eisenmenger, N., Giljum, S., & Jackson, T. (2017). Material flow accounting: Measuring global material use for sustainable development. *Annual Review of Environment and Resources*, *42*(1), 647–675. https://doi.org/10.1146/annurev-environ-102016-060726

Social capital

h) Dasgupta, P. (2021). *The economics of biodiversity (The Dasgupta Review)*. HM Treasury. https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review.

Especially relevant is the chapter on "Laws and norms as social institutions" (Ch. 6, pp 167-187).

i) Hamilton, K. E., Helliwell, J. F., & Woolcock, M. (2016). *Social capital, trust, and well-being in the evaluation of wealth* (No. WPS7707; pp. 1–23). The World Bank. http://documents.worldbank.org/curated/en/249031468195550873/Social-capital-trust-and-well-being-in-the-evaluation-of-wealth

A seminal paper on the links among well-being, trust, and social capital

j) Schlager, E., & Ostrom, E. (1992). Property-Rights Regimes and Natural Resources: A Conceptual Analysis. *Land Economics*, *68*(3), Article 3. https://doi.org/10.2307/3146375

This reading is especially interesting in light of our experience playing Fishbanks. It studies in detail different varieties of property rights regimes or design (institutional arrangements) and the impact of different property rights regimes on the sustainability of fisheries management in a lobster fishery in Maine.

k) Edelman. (2024). *Why we study Trust*. Edelman. https://www.edelman.com/trust

Read the current "Trust barometer report" and other links on this page to see how strategies for monitoring and building trust have become a part of good business.

Knowledge capital

l) Conway, G., & Waage, J. (2010). *Science and Innovation for Development*. UK Collaborative on Development Sciences (UKCDS).
This work is dated, but still provides one of the best overall perspectives on the subject.

m) Anadon, L. D., Chan, G., Harley, A. G., Matus, K., Moon, S., Murthy, S. L., & Clark, W. C. (2016). Making technological innovation work for sustainable development. *Proceedings of the National Academy of Sciences*, *113*(35), 9682–9690. https://doi.org/10.1073/pnas.1525004113
Synthesis of a major project digging into the multiple processes from invention to retirement that go into the making of innovations that serve the public good.

n) Roser, M. (2024). *Our world in data*. https://ourworldindata.org/
The amazing *Our World in Data* website has many different datasets that help us understand current trends in knowledge capital. Explore the website "Topics" on "Education and Knowledge" and on "Innovation and Technological Change" to find datasets that address some aspect of knowledge capital you are interested in. Think about whether the data being reported is a stock or a flow measurement for knowledge capital.

Unit 1.5 Integrated assessment of resource trends: Are we consuming too much?

Previous Units argued that resource stocks -- natural and anthropogenic -- can usefully be thought of as the ultimate determinants of sustainable development. And that progress in the pursuit of sustainability goals – cast in terms of non-declining and inclusive social well-being -- should be measured by tracking changes in the aggregate social value or wealth represented by the bundle of all relevant resource stocks. The question we begin to address in this Unit is how to do the aggregation. We focus here on retrospective sustainability assessments, i.e. evaluating whether recent and current development trends are sustainable. (A typical question we seek to answer is "Are the prospects people have for improving their lives and the lives of their descendants better now than they were a decade ago?") We turn in later units – after exploring the dynamics of nature-society systems -- to the prospective policy analysis of whether particular interventions would be likely to promote improvements in the pursuit of sustainability. (There we will explore how to address questions such as "Is the wetland restoration project being proposed likely to increase well-being?"[*])

A useful focus for retrospective sustainability assessments is the question "Are we consuming too much?" At the most fundamental level "too much" consumption for development to be sustainable would occur if the gross environmental damage done to natural resources in the course of (say) building a hydroelectric project were greater than the value added to society through the resulting increase in its manufactured capital. One such assessment is discussed in the "environmental accounting" section of first reading listed below. A more comprehensive sustainability assessment would examine whether the value to society of all resources consumed (depleted) in the course of development was "too much" in the sense that it was greater than the value of the investments in other resources enabled by those depletions. This is the thrust of cutting-edge work on "inclusive wealth" assessments covered in the readings. Such assessments are not yet comprehensive and face significant empirical and theoretical challenges. But, as we will discuss in Part III of this course, they are already being implemented by the UN, World Bank, national governments and other organizations around the world in their pursuits of sustainability.

Preparation for class:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Read "Toward the Integration…" (pp. 50-51), and "Accounting and Indicator Systems" (pp. 75-81).

b) **Read**: Dasgupta, P., Managi, S., & Kumar, P. (2021). The inclusive wealth index and sustainable development goals. *Sustainability Science*. https://doi.org/10.1007/s11625-021-00915-0 (4pp)

c) **Review as needed**: Case study for the Alaska Salmon Fishery introduced in Unit 1.1 (Thompson, M. (2021). *The Alaskan Salmon Fishery: Managing Resources in a Globalizing World* (Course Library for Sustainable Development Course). Harvard University.) Available in the Course Library.

Study Questions to help you get the most out of the readings:

The readings discuss two of the many approaches to retrospective sustainability assessment: GED/VA (gross environmental damage relative to economic value added) and IW (inclusive wealth). Compare and contrast the two approaches as you think about the following questions:

I. **Inclusiveness**: All assessment approaches, as a practical matter, must leave out many of the resources we would ideally like to see included in our efforts to understand whether development trends are sustainable. Of the natural and anthropogenic resources discussed in previous Units, which are included and excluded by each of the two approaches presented in the readings? How do

[*] The two specific example questions, and much of the deeper argument made here, are from the Dasgupta 2021 publication listed in the "Digging deeper…" readings for this Unit.

their respective decisions regarding what resources to include affect the implications of their findings for assessing the sustainability of recent trends in development?

II. **Granularity**: The two approaches are quite different in the granularity of their assessments, including both the extent to which they lump different kinds of resources into single categories, and the extent to which they actually aggregate trends in natural and anthropogenic resources to produce single metrics of sustainability. What are those differences? What are the advantages and disadvantages of each approach? For what assessment questions is each most useful?

III. **Connections**: Both assessment approaches largely ignore connections among countries, e.g. transboundary pollution or trade in goods and services. We explore those connections in more detail in Part II of the course. It's worth considering here, however, how you would expect inclusion of such connections to change the results of the assessments. And what might be the greatest barriers to incorporating such connections in updated versions of the assessments?

IV. **Equity**: To what extent do the two approaches inform the equity dimension of sustainability goals? How might they be extended to illuminate equity considerations more effectively?

V. **Sustainability assessment of the Alaskan salmon fishery:** Based on the GED/VA and inclusive wealth approaches discussed in the readings:
- Using the GED/VA approach from Matson, what specific environmental damages from fishing activities would need to be weighed against the economic value added by the fishery?
- Which capital assets in the Alaska salmon fishery case would be included in an inclusive wealth assessment (be specific about both natural and anthropogenic resources/capital assets? Which important assets might be difficult to value in monetary terms?
- If these two approaches gave divergent signals about the Alaska fishery - for instance, if GED/VA showed net environmental damages while inclusive wealth showed growing total capital stocks - what would each be telling you about the fishery's sustainability? What might account for such differences? All of these perspectives considered, are we consuming too much from the Alaska fishery for its current development pathway to be sustainable?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

d) Arrow, K. J., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Levin, S. A., Mäler, K.-G., Schneider, S., Starrett, D., & Walker, B. H. (2004). Are We Consuming Too Much? *Journal of Economic Perspectives*, *18*(3), Article 3..
This is a classic paper that advanced the "consuming too much" framework that evolved into today's inclusive wealth work.

e) Muller, N. Z., Mendelsohn, R., & Nordhaus, W. D. (2011). Environmental accounting for pollution in the United States economy. *American Economic Review*, *101*(5), 1649–1675.
An elegant example of the "gross environmental damages" approach to sustainability accounting, expanding on the summary given in reading 'a'.

f) Dasgupta, P. (2021). *The economics of biodiversity (The Dasgupta Review)*. HM Treasury. https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review. For a full exploration of the inclusive wealth approach to sustainability assessment, explore "Sustainability assessment and policy analysis" (Ch. 13, pp. 323-358) and "Accounting prices and inclusive wealth" (Ch. 13*, pp. 359-364).
This is one of the most up-to-date expositions on how to better measure progress toward sustainability. Despite its title, it is not just about biodiversity but rather the whole suite of natural and anthropogenic resources addressed in this course. Significantly, it was commissioned – and is being used -- by the UK Treasury.

Unit 2.1 System Dynamics: How can we analyze interactions of nature and society?

Part I of this course presented a largely static view of the relationships among human well-being, nature and society. But sustainable development is ultimately about the dynamics of those relationships – how they change through time. The Fishbanks exercise carried out as a "warm up" for this course in its Unit 0.2 explored the simple dynamics of how one year's choices about how many boats to build and how many fish to catch changed both the bank accounts of the fishers and the number of fish available for harvest a year hence. More generally, the assessment of resource trends with which we concluded Part I invited us to consider whether society's current consumption of resources to support its own well-being would leave enough resources for future generations to provide comparable levels of well-being for themselves. Answering these questions about changes in resources through time requires an understanding of how nature and society interact as a system – how the state of each is simultaneously both a consequence and a cause of changes in the other.

This unit introduces Part II of the course in which we will draw on the science of complex adaptive systems to understand and forecast the dynamics of nature-society interactions. Following an overview of "systems thinking" in this unit 2.1, we will then dive more deeply into system properties particularly relevant to sustainability: stocks, flows and feedbacks that shape resource dynamics (Unit 2.2); nonlinearity, tipping points and path-dependence that make ubiquitous "big effects from small causes" (Unit 2.3), horizontal connections through which processes such as pollutant flows, human migration, and the spread of ideas partially couple the dynamics of different places around the world (Unit 2.4), vertical connections through which micro- and macro-scale processes interact with one another to reshape phenomena as different as impacts of climate change and the spread of innovations (Unit 2.5), the actors, institutions and power dynamics through which people seek to change development pathways (Unit 2.6), and the inequalities that emerge from those efforts (Unit 2.7). Part II closes with a synthesis of all these elements and relationships into a more detailed version of the framework for analyzing sustainability that was introduced earlier in the course (Unit 2.8).

To prepare for this first unit of Part II, please:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Read pp. 52-57, end of first sentence.
We will continue to use the Matson et al. book to keep the "big picture" of the pursuit of sustainability in the foreground as we dive into particular topics throughout the course. The material covered in the readings assigned here provides an introduction to how and why "systems thinking" is essential for understanding the dynamics of nature-society systems, and for evaluating the likely consequences of interventions intended to guide those dynamics toward sustainability.

b) **Watch**: Sweeney, L. B. (Director). (n.d.). *In a world of systems* [YouTube]. Donella Meadows Institute. https://youtu.be/A_BtS008J0k (9 mins.)
This short video, based on the teachings of the late systems thinking guru Donella Meadows, provides a whimsical and accessible but deep introduction to the topic.

c) **Read**: Sterman, J. (2002). *System Dynamics: Systems Thinking and Modeling for a Complex World* [Working Paper]. Massachusetts Institute of Technology. Engineering Systems Division. https://dspace.mit.edu/handle/1721.1/102741
MIT's Jay Forrester and John Sterman pioneered the application of systems thinking to analysis of complex systems and policies for their management in the 2nd half of the 20th Century. Their motivation was the blunders they found their colleagues and students making in extrapolating linear thinking and single-cause/single-effect analysis to complex real world problems. Their initial applications were to urban design and business management, but later applications extended into the realms of resource management (Sterman is author of the Fishbanks game we explored earlier in the course, climate change and sustainability more broadly. The first sections of this working paper

provide an introduction to their approach. Subsequent units of the course will pick up on later sections and applications.

d) **Review**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Section on the case study "London: The struggle for sustainable development in an urban environment" (pp. 143-165; originally assigned in Unit 1.4).

Study Questions to help you get the most out of the readings:

Return to the London case study you analyzed in Part I. Recall that the analysis was as an exercise in qualitatively mapping the connections among capital asset stocks, flows in and out of those stocks due to human activities, and consequences for well-being. Think of those as the elements that would be needed for a systems analysis of the dynamics of nature-society interactions in the period in London you focused on. Starting with one human activity, think through the following:

I. How did it alter human well-being in the short term? Long term?

II. What are the most significant "examples of policy resistance" (Sterman, exhibit 1) that it encountered?

III. What are the processes connecting it to stocks and flows of assets and to and well-being?

IV. What are the most significant time lags in the causal chain connecting your chosen activity to impacts on well-being?

V. Which are the characteristics of dynamic systems most relevant to nature-society interactions in London you are trying to explain? (Consider the checklist of candidates in Exhibit 2 in the Sterman reading 'c').

VI. Your case?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

e) More extended readings on dynamics of nature-society interactions in the Anthropocene system are listed in the Matson et al. course book Under Appendix B: Additional Resources (pp. 202ff). See especially the entries there for Chapter 3 (pp. 205-206).

f) Here are two classic primers in general systems thinking and modeling that will repay any time you can give to them:
   - Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.
   - Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.

Unit 2.2 Stocks and flows: How do these fundamental properties of nature-society interactions shape their dynamics as adaptive systems?

Part I of the course introduced stocks of resources as the fundamental determinants of sustainable development, and some of the flows through which those stocks are depleted or enhanced by human activity. We began Part II of the course in the previous Unit, arguing that stocks, flows and feedbacks among them are fundamental components of any system, and that seeing them as such can help to understand the dynamics of the nature-society systems that are central to sustainable development. In this Unit, we explore those concepts more deeply, emphasizing:

- How **stock-flow relationships** can produce counterintuitive results that if not properly understood can lead to debilitating management blunders;
- How **feedback loops** cause changes in one stock (part or component) of the system (e.g., building a levee on a river) to cause changes in flows (e.g. reduce flooding of adjacent farmland) that affect other properties of the system (e.g. the incentives for people to settle in the newly protected flood plain) and may eventually loop back to influence that initial stock itself (e.g. building more or higher levees to protect the new settlements);
- How feedbacks allow nature-society interactions to function as ***adaptive* systems** in which departures from desired or expected development pathways can be responded to in hopes of achieving various goals (e.g. the levee example above, in which both levee planners and floodplain settlers adapt);
- How systems exhibit **emergent properties** that are more than the sum of their component parts and cannot be understood, much less adaptively managed, without careful analysis of underlying stocks, flows and (adaptive) feedbacks (e.g. the unexpected emergence of a better protected but also more heavily built up and thus potentially vulnerable floodplain as a consequence of initial efforts to protect a few farmers).

The principal means for connecting these concepts to system dynamics is through models. These can be mathematical but need not be: the key is that models unambiguously specify what elements are included in an analysis and how they relate to one another. We've already seen one example of such models for understanding system dynamics in the Fishbanks simulation explored at the beginning of the course, in which fishers attempted to adapt their fleets to changing conditions of the fishery. In this Unit we will further explore models as a means for understanding system dynamics through hands-on work using the multi-agent programmable modeling environment "NetLogo" to address the challenge of climate change.

To prepare for this Unit, please:

a) **Read**: Matson, P. A., Clark, W. C., & Andersson, K. P. (2016). *Pursuing sustainability: A guide to the science and practice*. Princeton University Press. https://pursuing-sustainability.stanford.edu/ . Continue with Ch. 3 "Dynamics of social-environmental systems," pp. 57–63 (stop at the heading "Complexity…." there).

b) **Read**: Sterman, J. (2002). *System Dynamics: Systems Thinking and Modeling for a Complex World* [Working Paper]. Massachusetts Institute of Technology. Engineering Systems Division. https://dspace.mit.edu/handle/1721.1/102741

c) **Explore:** Clark, W. C., & Harley, A. G. (2025). *NetLogo Guide for Sustainable Development Course*. Harvard University. (Unpublished ms, available in the Course Library). Explore Sections 1 "Basic access" and 2 "NetLogo stocks and flows model."

d) **Read**: Iler, S., & Clark, W. (2025). *NetLogo: Exploring Stocks and Flows for Climate Change*. Harvard University. 1 pg. (Unpublished ms, available in the Course Library).

Study Questions to help you get the most out of this unit:

I. Run the NetLogo "Stocks and Flows model" along the lines introduced in (d) above. For the model run in which you come closest to achieving your goal, write down answers to the following questions, which are also posed under the section "Things to notice and things to do" in the "Model Info" drop down of the "Stocks and Flows model" accessed through reading 'd' above:
   a) In which year did you first stabilize the amount of atmospheric carbon?
   b) How much carbon was in the atmosphere when it stabilized? (Your answer should have units of Gt C.)
   c) What was the annual emissions of carbon in the year that you achieved stabilization of the amount of atmospheric carbon? (Your answer should have units of GtC/y.)
   d) In a sentence or two, describe the shapes of your final graphs of "Atmospheric Carbon" and "Emitted by Society" and their relation to one another.
   e) In a few sentences, describe to someone just starting this exercise the strategy you devised that came closest to achieving your goal.

II. What makes it hard to adaptively manage emission flows as a means of achieving the goal of keeping carbon stocks in the atmosphere below a given threshold? Given what you have learned in using the model, what would you recommend to decision makers in the real world about how they should design a schedule of changes in the flow of emissions that would help to achieve the goal of limiting carbon stocks in the atmosphere while minimizing disruptions to the energy system? What pitfalls would the modeling exercise suggest that you should warn them about as likely to make it harder for them to achieve their goals?

III. All models are simplifications of the real world. What simplifications made in the NetLogo climate model might lead you to draw conclusions from it that are seriously at odds with how dynamics in the real world play out? How do you think the real-world dynamics are likely to differ from those of the model? Are the most problematic simplifications about stocks, flows, feedbacks, adaptation or something else? Why?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

e) Continue to browse the two classic primers in general systems thinking and modeling originally listed in the "Digging Deeper" section of Unit 2.1:
   - Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.
   - Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.

f) The NetLogo modeling environment introduced in this unit is much more thoroughly developed in: Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modeling: Modeling natural, social, and engineered complex systems with NetLogo*. The MIT press. https://www.intro-to-abm.com/ (https://www.intro-to-abm.com/).

g) These two papers are referred to in the reading 'd' above, and can be explored for more details on the argument summarized there:
   - Sterman, J. D. (2002). All models are wrong: Reflections on becoming a systems scientist. *System Dynamics Review*, *18*(4), 501–531. https://doi.org/10.1002/sdr.261
   - Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249–286. https://doi.org/10.1002/sdr.198

Unit 2.3 Complexity: How are the dynamics of nature-society systems shaped by their complexity and the non-linearities, multiple regimes and tipping points that emerge from it?

Nature-society interactions constitute not only *adaptive* systems, as discussed in the previous unit, but *complex* adaptive systems. Three fundamental attributes of nature-society systems have been shown to make them *complex* adaptive systems rather than just *adaptive* ones (the back story for these assertions is provided in the Levin et al 2013 paper listed below under "Digging Deeper…."):

- **persistent heterogeneity** (individuality, diversity) of their basic elements [e.g. fishing towns and mining towns are and remain distinctive nature-society systems rather than being generic and interchangeable ones];
- **local interactions** (relationships) among those heterogeneous elements that are local or context specific [e.g. neighboring fishing towns interact differently with one another depending on whether they compete for coastal lobsters or oceanic swordfish];
- **autonomous selection** processes that enhance some elements (but not others) based on the outcome of the local interactions [e.g. fishing towns that learn to harvest sustainably will (one hopes) prosper by attracting more investment and retaining more young fishers than those that don't, and wither].

These attributes of complex adaptive nature-society systems give rise to an array of far-from-equilibrium dynamics that are fundamentally important for the pursuit of sustainability, including:

- **non-linear responses** to interventions, which are in play whenever repetitions of the same action (cause) do not always produce the same result (effect) [e.g. Push a book sideways across a table by snipping it with your finger. Each snip moves the book by about the same amount until its position reaches the edge of the table, at which point the same snip has a very different result. Mathematically, y=mx is a linear system because the "effect" on y of a change in the "cause" x is always the same regardless of the initial value of x. Whereas y=mx^2 (i.e. x raised to the power of 2) is a nonlinear system because the effect on y of a given change in x depends on the initial value of x].
- **Regimes** are particular sets of dominant relationships, feedbacks, or other "rules of the game" (both natural and social) that give rise to characteristic dynamics of development pathways [e.g., fossil-fuel energy regimes, intensive agriculture regimes] in nature-society systems. Characteristic of regimes is that within them, small perturbations—whether caused by chance, internal dynamics, or outside disturbances—encounter feedbacks that tend to push the system back toward its earlier state or to lock in the development pathway. Separating neighboring regimes are thresholds (also called "tipping points")...
- **Thresholds or tipping points** seem to turn up everywhere in nature-society systems. We'll explore formal definitions of "tipping points" in the readings. But your intuition is probably about right if you think of "tipping points" as "points of no return" beyond which system dynamics get quickly and irretrievably very different: YouTube segments that go from a few shares to viral, taking a curve too fast on a mountain road, bursting a speculation bubble, melting the Greenland Ice Cap, etc. We care about tipping points because they undermine our ability to seek sustainable development by just trial and error feedback or, as a famous political science paper puts it, by "muddling through."

To prepare for this Unit, please:

a) **Read:** Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Read Ch. 3 "Dynamics of social-environmental systems," pp. 63 (start with "Complexity") – pg. 70 (stopping at the heading "Evaluating complex systems").

b) **Experiment**: Conduct the paper-folding experiment in non-linear systems described in Clark, W. C., & Harley, A. G. (2025). *Non-linear behavior in paper folding*. Harvard University. (Unpublished MS, available in Course Library).

c) **Explore:** Clark, W. C., & Harley, A. G. (2025). *NetLogo Guide for Sustainable Development Course*. Harvard University. (Unpublished ms, available in the Course Library). For this Unit, reread Section 1 and explore Section 3 "Netlogo fire model."

With this material, we continue our use of simple models to develop an appreciation of how complex and often unexpected system dynamics can arise from very simple system structures. This fire model captures common elements of the spread of disease, rumors or innovations.

Study Questions to help you get the most out of the readings:

I. Explain the result of your paper-folding experiment assigned in (b) above. Is the difficulty of doing a fold the same regardless of how many folds have already been made? Why? In crafting your explanation, consider whether your conclusion would be different if you had used a bigger sheet of paper. (It may help to compare your result with the single sheet of typing paper to the experience of a Myth-Buster group trying the same experiment with a foot-ball-field sized tarp: https://youtu.be/65Qzc3_NtGs?si=bIaHy4FsfrAnSyzo ; 4 min). What nature-society interactions display relationships like those found in the paper-folding experiment?

II. Use the NetLogo fire model described in (c) above to explore how the thresholds arise in complex systems, and to get a feel for their implications for adaptive management. In particular, how does initial forest density relate to the % of the forest that burns? Is the relationship linear (a unit change in density always results in the same amount of change in the % of the forest that burns) or does it exhibit discontinuities or tipping points? Why? What are the implications for management? Would it make sense to design different strategies for managing a low density forest "regime" and a high density one? What other nature-society interactions display relationships like those found in the simple fire model?

III. Think back to the system dynamics of the Fishbanks game that you played in Unit 0.2. Describe the role of trial-and-error in your management of that complex adaptive system, with special attention to your goal, the trial of your action intended to achieve the goal, the measurement of the actual impact of your action, your assessment of what worked vs. what turned out to be an error, and what adaptation you adopted for the next round of play. What were the successes of your approach to adaptive management? Where and why did it fall short. How could modeling the system help to improve your trial and error management?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

d) **Read**: Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., & Arrow, K. (2013). Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics*, *18*(2), 111–132.

This paper lays out the fundamentals and practical implications of its title.

e) **Read:** Biggs, R., Peterson, G. D., & Rocha, J. C. (2018). The Regime Shifts Database: A framework for analyzing regime shifts in social-ecological systems. *Ecology and Society*, *23*(3), 9–9. https://doi.org/10.5751/ES-10264-230309

This paper introduces the 'Regime Shifts Database', an open-access database that synthesizes information on regime shifts in nature-society across a wide range of scales.

f) **Read:** 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. https://doi.org/10.1073/pnas.1810141115

This paper takes the concept of tipping points to environmental systems operating at global scale, examining how human activities may push the climate into "no-analog" regimes beyond the experience of civilization. The tipping point figure is worth careful study.

g) **Read:** Barrett, C. B., Travis, A. J., & Dasgupta, P. (2011). On biodiversity conservation and poverty traps. *Proceedings of the National Academy of Sciences*, *108*(34), 13907–13912. https://doi.org/10.1073/pnas.1011521108

This paper reminds us that "tipping points" are not necessarily bad by emphasizing the goal of helping impoverished societies to cross a tipping point beyond which lies an escape from poverty traps into a regime of potentially self-reinforcing growth in well-being.

Unit 2.3 Complexity: How are the dynamics of nature-society systems shaped by their complexity and the non-linearities, multiple regimes and tipping points that emerge from it?

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a) **Read:** Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. Read Ch. 3 "Dynamics of social-environmental systems," pp. 63 (start with "Complexity") – pg. 70 (stopping at the heading "Evaluating complex systems").

b) **Experiment**: Conduct the paper-folding experiment in non-linear systems described in Clark, W. C., & Harley, A. G. (2025). *Non-linear behavior in paper folding*. Harvard University. (Unpublished MS, available in Course Library).

c) **Explore:** Clark, W. C., & Harley, A. G. (2025). *NetLogo Guide for Sustainable Development Course*. Harvard University. (Unpublished ms, available in the Course Library). For this Unit, reread Section 1 and explore Section 3 "Netlogo fire model."

With this material, we continue our use of simple models to develop an appreciation of how complex and often unexpected system dynamics can arise from very simple system structures. This fire model captures common elements of the spread of disease, rumors or innovations.

Study Questions to help you get the most out of the readings:

I. Explain the result of your paper-folding experiment assigned in (b) above. Is the difficulty of doing a fold the same regardless of how many folds have already been made? Why? In crafting your explanation, consider whether your conclusion would be different if you had used a bigger sheet of paper. (It may help to compare your result with the single sheet of typing paper to the experience of a Myth-Buster group trying the same experiment with a foot-ball-field sized tarp: https://youtu.be/65Qzc3_NtGs?si=bIaHy4FsfrAnSyzo ; 4 min). What nature-society interactions display relationships like those found in the paper-folding experiment?

II. Use the NetLogo fire model described in (c) above to explore how the thresholds arise in complex systems, and to get a feel for their implications for adaptive management. In particular, how does initial forest density relate to the % of the forest that burns? Is the relationship linear (a unit change in density always results in the same amount of change in the % of the forest that burns) or does it exhibit discontinuities or tipping points? Why? What are the implications for management? Would it make sense to design different strategies for managing a low density forest "regime" and a high density one? What other nature-society interactions display relationships like those found in the simple fire model?

III. Think back to the system dynamics of the Fishbanks game that you played in Unit 0.2. Describe the role of trial-and-error in your management of that complex adaptive system, with special attention to your goal, the trial of your action intended to achieve the goal, the measurement of the actual impact of your action, your assessment of what worked vs. what turned out to be an error, and what adaptation you adopted for the next round of play. What were the successes of your approach to adaptive management? Where and why did it fall short. How could modeling the system help to improve your trial and error management?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

d) **Read**: Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., & Arrow, K. (2013). Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics*, *18*(2), 111–132.

This paper lays out the fundamentals and practical implications of its title.

e) **Read:** Biggs, R., Peterson, G. D., & Rocha, J. C. (2018). The Regime Shifts Database: A framework for analyzing regime shifts in social-ecological systems. *Ecology and Society*, *23*(3), 9–9. https://doi.org/10.5751/ES-10264-230309

This paper introduces the 'Regime Shifts Database', an open-access database that synthesizes information on regime shifts in nature-society across a wide range of scales.

f) **Read:** 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. https://doi.org/10.1073/pnas.1810141115

This paper takes the concept of tipping points to environmental systems operating at global scale, examining how human activities may push the climate into "no-analog" regimes beyond the experience of civilization. The tipping point figure is worth careful study.

g) **Read:** Barrett, C. B., Travis, A. J., & Dasgupta, P. (2011). On biodiversity conservation and poverty traps. *Proceedings of the National Academy of Sciences*, *108*(34), 13907–13912. https://doi.org/10.1073/pnas.1011521108

This paper reminds us that "tipping points" are not necessarily bad by emphasizing the goal of helping impoverished societies to cross a tipping point beyond which lies an escape from poverty traps into a regime of potentially self-reinforcing growth in well-being.

Unit 2.4 Horizontal connections: How do linkages among places – e.g. pollution externalities, trade, and migration -- affect the pursuit of sustainability?

The course so far has emphasized two perspectives on sustainable development: one broadly global (e.g. the resource trends of Part I), the other focused on particular places (e.g. our teaching cases for London, Alaska and Appalachia). With this Unit we seek to bridge these two perspectives, acknowledging that local places are connected with one another on a global stage. Those connections are ubiquitous, involving flows of people, pollution, trade, finance, information, and other things we review in the readings. But they are also incomplete: the Anthropocene System remains heterogeneous in the face of connections rather than becoming homogenized: Vietnam and France, for example, remain distinct entities even though they are partially connected in many ways. Efforts to analyze the dynamics of nature-society systems therefore must take seriously both the persistent heterogeneity of different patches of the Anthropocene system and the partial connections among them.

What connections among places matter for sustainability? Some are clearly damaging to human well-being, inequitable in their consequences, or otherwise inconsistent with the goals of sustainable development, e.g. the spread of diseases from their points of origin into global pandemics; the enslavement of people from some places and their forceable removal to serve the interests of people in other places; the violent extraction of all manner of natural resources (fur, gold, cotton) from around the world by a handful of colonial actors; the unilateral export of pollution and other forms of waste from places that benefit from the production and consumption that generate the pollution to places that only experience its harms.

Other connections among places have arguably produced benefits to society as a whole, distributed them more equitably, or may be otherwise consistent with the pursuit of sustainability, e.g. the spread of "foreign" crops from their places of origin to become staples grown around the world (e.g. corn, wheat, potatoes, tomatoes); the migration of people from one place to another in search of a better life for themselves and their children can also benefit the places they immigrate to and (through remittances) the places they emigrated from; fair trade, allowing people in one place to take advantage of its comparative advantages in ways that benefit both local producers and consumers in places far away; knowledge produced in particular places that have invested in heavily in research promotes local benefits but also spills over to places that have done nothing to create it. Still other connections among places clearly play a role in the dynamics of the Anthropocene, but whether they support or impede sustainable development is unclear or depends on local context.

Analysts seeking to understand and promote sustainability need some organized way of sorting through the vast set of possible connections among places to focus on those most important for the pursuit of sustainability. We still lack (and may well never have) a grand theory of connections. But some progress is being made as is illustrated in the Readings listed below[*].

To prepare for this Unit, please:

a) **Read / review:** Matson, P. A., Clark, W. C., & Andersson, K. P. (2016). *Pursuing sustainability: A guide to the science and practice*. Princeton University Press. https://pursuing-sustainability.stanford.edu/**.** Read Ch. 3 "Dynamics of social-environmental systems," pp. 61-63

[*] Terminology Alert: The field of sustainability science is evolving rapidly, and we still struggle to find simple but meaningful terms for core ideas. For this course, "Connections" used in this class = "horizontal connections" from the syllabus and the Synthesis we provide in Unit 2.8. It means flows of materials, organisms or information from one place to another, and implies a global (or at least multi-place) perspective. "Invisibilities" is a term we used in the Matson et al. book to mean several things, one of which is a local perspective on the "connections" used here. "Vertical connections", a term used in the syllabus is something else altogether which we will explore in Unit 2.5. Just ignore it for now. Sorry.

("Invisibilities in space and time"). Review case study "London: The struggle for sustainable development in an urban environment," pp. 143-165.

b) **Read**: Hull, V., & Liu, J. (2018). Telecoupling: A new frontier for global sustainability. *Ecology and Society*, *23*(4), art11. https://doi.org/10.5751/ES-10494-230441 . Read the entire 7 pages of text and figures.

This paper discusses many of the kinds of horizontal connections that have turned out to matter for sustainable development. It is not comprehensive, lacking for example more than passing mention of the long range transport of air pollution. But you should extract from it and your own reflections a check list of what may be moving from one place to another.

c) **Read:** Harley, A. G. (2021). *Looking outward: Refocusing attention on London's hinterland (Addendum to London: A multi-century struggle for sustainable development in an urban environment)* (Course Library for Sustainable Development Course). Harvard University. (Available in Course Library).

This paper extends the London case study you read earlier to explore the city's "horizontal connections" with the rest of the world. It gives special attention to the resources that London, as capital of a colonialist empire, drew from around the world to support its growth and recovery from disaster.

d) **Review:** Thompson, M. (2021). The Alaskan Salmon Fishery: Managing Resources in a Globalizing World. Harvard University. (Available in Course Library pp. 1-25).

e) **Explore:** Clark, W. C., & Harley, A. G. (2025). NetLogo Guide for Sustainable Development Course. Harvard University. (Available in the Course Library). Review Section 1 "Basic access" and explore Section 4 "NetLogo fire with connections model" (Netlogo's title for this model is "Fire simple extension 3").

Study Questions to help you get the most out of the readings:

I. Use the "Netlogo fire with connections model" introduced in (d) to explore how connections change the system dynamics and thresholds that you encountered in the "Netlogo fire model" of the previous Unit. Note that simple fire model already involved some modest connections: the fire spread (connected) only to adjoining cells and only if those cells contained unburned forest. Low densities of forest increased the chances that the fire would have no unburned forest patches adjoining it, and would therefore die out. (Think of parallels with epidemics). The "Connections" variant of the simple model introduced in this Unit allows you to explore how various more complex connections of the system change its behavior. Start with an initial density of the forest close to what you identified in the previous unit as the threshold value that determined whether the fire would spread across the entire landscape and "homogenize" it. How does "wind speed" change the dynamics? "Wind direction?" Why? What are the implications for managing forests? What are analogs to wind speed and direction that might matter in other cases of connected dynamics, eg. migration, epidemics, 'viral' social media? How would they matter for management? The big change in this version of the fire model is what it calls "big jumps," i.e. the ability of fire to jump over the cells that contain no unburned forest and therefore would have stopped its spread in the simple model. What is the impact of turning on the "big jump" switch in the model? What are the implications for fire management? What could cause "big jumps" in real forest fire situations? What analogs to "big jumps" do you think can you think of as affecting the dynamics of other nature-society interactions? What are their implications for the pursuit of sustainability?

II. Connections with other places can have an important role in shaping the prospects for sustainability. How do the connections between in-shore and off-shore fisheries affect sustainability in Fishbanks?

III. For the London case review the original text but focus on the Addendum from the assigned readings for this Unit. When resources were low or depleted how did London rebuild its asset stocks? What role did connections play? What were the consequences for the places to which London connected?

IV. For the case study of the Alaska fishery introduced in Unit 1.1:
   a) Identify ONE connection that is highly relevant to the pursuit of sustainability between the place that is the focus of the teaching case and some other place(s) in the world. Describe the connection in terms of both the flows involved (what it is that is being moved from one place to the other, e.g. people, pollution, ideas, etc.) and the stocks that are thereby changed. Note that the impacts on stocks caused by the connection can be at either end of the flow, i.e. of the teaching case on somewhere else, or of somewhere else on the teaching case, or of both). Explain why you picked the connection you did, rather than one of the other possible connections identified in this note or in the readings.
   b) What is the system structure or process through which the connection you identified in (1a) occurs, e.g. migration, air movement, communication?
   c) What modification of the structures or processes you identified in (b) could best advance the pursuit of sustainability? Explain your answer.

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

f) **Read:** Liu, J. (2023). Leveraging the metacoupling framework for sustainability science and global sustainable development. *National Science Review*, *10*(7), nwad090. https://doi.org/10.1093/nsr/nwad090

This paper provides an in-depth review of the multiple sorts of horizontal connections that affect development pathways and their prospects for sustainability.

Unit 2.5 Vertical connections: How does the ubiquitous generation and propagation of novelty in the Anthropocene System affect the pursuit of sustainable development?

The previous Unit reviewed the ways in which particular places are connected with one another. The connections included both natural or anthropogenic flows involving materials, energy, or information. The places included households, firms, communities, states, regions, etc. We focused implicitly on linkages among places at the same hierarchical level, which we captured in the term "horizontal connections." We argued that while horizontal connections are ubiquitous in nature-society systems, they are often incomplete. The result is persistent heterogeneity and individuality of different places in the Anthropocene System. Implications for the system's dynamics are profound.

In this Unit we turn to a second kind of connections: those that provide vertical linkages across hierarchical levels of the Anthropocene System. These, too, are ubiquitous and multi-directional, encompassing such phenomena as the impact of global climate change on local well-being, the impact of local industrial emissions on global climate and, more generally, vertical connections among macro, meso and micro levels of system activity. We focus here, however, on one very particular group of vertical connections with enormous implications for sustainable development: those connections involved in the generation and propagation of novelty in the Anthropocene System. Novelty can take biological, technological, or institutional forms. Its emergence is facilitated by the persistent heterogeneity of that system noted above. It usually originates under very specific local or niche conditions (e.g. the legendary garages of Silicon Valley, or the Wuhan markets of covid). But when such local or micro-level novelty is taken up at higher levels, it can spread rapidly and change the dynamics of larger systems.

What forms of novelty matter for sustainability? Some are clearly damaging to human well-being, inequitable in their consequences, and inconsistent with the goals of sustainable development. For example: the emergence of novel zoonotic diseases made increasingly likely human actions including deforestation and over-crowded and unsanitary rearing of animals for consumption; the invention of some technologies including things like toxic chemicals in widely-use flame retardants and non-stick cookware; the emergence and spread of conspiracy theories and 'fake news' and the related re-emergence and spread of autocratic governments.

Novelty has also led to more equitably distributed benefits to society as a whole and may be consistent with sustainable development. For example: the invention of high-yielding rice and wheat crops as part of the Green Revolution that led to increasing food production around the world that more than kept pace with the rapid population growth of the 20th century; The development of antiretroviral drugs capable of treating the HIV virus; the emergence of spread of values like our own courses focus on the importance of intra- and inter-generational equity.

Still other novel developments -- whether biological, technological or institutional -- clearly play a role in the dynamics of the Anthropocene. But whether they support or impede sustainable development depends on context. The pursuit of sustainability is centrally about learning how to help generate novelty at the micro-level and to propagate promising results to meso- and macro-levels through the management of vertical connections.

To prepare for this Unit, please:

a) **Read**: Geels, F. W., Kern, F., & Clark, W. C. (2023). System transitions research and sustainable development: Challenges, progress, and prospects. *Proceedings of the National Academy of Sciences*, *120*(47), e2206230120. https://doi.org/10.1073/pnas.2206230120
This article provides an updated account of how promoting the goal of transitions toward sustainability requires close attention to vertical connections and, particularly, the generation and propagation of innovation.

b) **Read**: Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

c) **Read**: Anadon, L. D., Chan, G., Harley, A. G., Matus, K., Moon, S., Murthy, S. L., & Clark, W. C. (2016). Making technological innovation work for sustainable development. *Proceedings of the National Academy of Sciences*, *113*(35), 9682–9690. https://doi.org/10.1073/pnas.1525004113

d) **Read**: Matson, P. A., Clark, W. C., & Andersson, K. P. (2016). *Pursuing sustainability: A guide to the science and practice*. Princeton University Press. https://pursuing-sustainability.stanford.edu/ . Read the case study, "An international success amid uncertainty: Ozone and the Montreal Protocol. pp. 179-186.

e) **Review as needed**: Case studies for London and Alaska introduced earlier in the course and available in the Course Library.

Study Questions to help you get the most out of the readings:

I. The readings highlight the important role of bottom-up innovations in the pursuit of sustainability. What innovation – in technology or policy – can you imagine that would best improve the prospects for sustainable development in Fishbanks? How did innovations affect the development pathway of the Stratospheric Ozone case presented in the Matson et al. book?

II. For the case studies on London and Alaska:
   a. Identify ONE source of novelty that is highly relevant to the pursuit of sustainability in the teaching case you have chosen to focus on. Is the novelty biological, technological or institutional? Explain how the source of novelty you picked is relevant to sustainability.
   b. What are the processes through which the novelty you identified in (a) initially emerges? What are the processes through which this novelty succeeds and spreads from the micro-level into the meso-level. *(Note that in the readings, the words level and scale are used to mean the same thing).*
   c. What modification of the structures or processes you identified in (b) above could best advance the pursuit of sustainability in your application region? Why?

III. For the sustainability challenge you selected as "your case," respond to the same 3 queries posed for the London and Alaska cases in II (above).

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

f) Geels, F. W. (2006). The hygienic transition from cesspools to sewer systems (1840–1930): The dynamics of regime transformation. *Research Policy*, *35*, 1069–1082. https://doi.org/10.1016/j.respol.2006.06.001

This piece explores the socio-technical transition from cesspool to sewer systems in the Netherlands. The conceptual section is a little weird, but the empirical case study nicely illustrates the complexities involved in shifting a socio-technical system from one state to another. We include it here, because it complements the London case and London's struggles to manage its own waste, but discusses the challenge in the language of innovation and vertical connectivity.

Unit 2.6 Actors, institutions and power: How does the unequal distribution of power among actors affect the pursuit of sustainability?

The pursuit of sustainable development is a massively redistributional agenda and thus often faces opposition from powerful incumbent interests intent on maintaining the status quo. Understanding development pathways in nature-society systems—with an eye towards fostering more sustainable pathways—requires examining the actors who shape nature-society systems, the institutional arrangements that govern their interactions, and the power dynamics that determine whose interests prevail.

In this unit, we explore how actors—entities with agency ranging from individuals to community groups to corporations to states—operate as agents within institutional contexts. Institutions, the formal and informal rules that structure human interactions, shape what actors may, must, or must not do in their interactions with one another and with nature. In the context of natural resource governance for example (such as a fishery), institutional arrangements help determine who has the right to harvest resources, who monitors compliance, who participates in decision-making, and how rules can be changed.

Central to understanding actor dynamics is the concept of power. We have found it most effective to use a three-dimensional view of power as a way of analyzing how actors use power within nature-society systems. Building on the scholarship of Steven Lukes and John Gaventa, we use a three-dimensional view of power outlined below and in greater detail in reading 'a':

1) **Compulsion (First Dimension):** Power derived from actors' ownership of or access to resources and their ability to compel others to act only on terms set by the powerful. This is the most visible form of power—the ability to prevail in open conflicts over decisions.
2) **Exclusion (Second Dimension):** Power derived from actors' ability to shape institutional structures, rules, and norms to serve their own interests, often by excluding others from decision-making arenas or keeping certain issues off the agenda entirely.
3) **Influence (Third Dimension):** Power derived from the ability to shape the goals, aspirations, values, beliefs, and even knowledge systems of others. This most subtle form of power can lead less powerful actors to internalize and accept their subordination as natural or inevitable.

These three dimensions of power reinforce one another to shape development pathways. When powerful actors control resources (first dimension), they can make rules to exclude challengers (second dimension) and promote narratives that make their dominance seem natural or beneficial (third dimension). However, this same framework reveals how power can be redirected toward sustainability: movements that shift values and narratives (third dimension, e.g. reframing development from GDP growth to wellbeing and SDGs) can change the status quo and open space for institutional reforms (second dimension, e.g. including indigenous peoples in resource governance), eventually enabling marginalized groups to gain control of resources (first dimension, e.g. indigenous lands, marine protected areas). Understanding how these dimensions interact is essential for identifying both barriers to and opportunities for advancing sustainable development.

Note: This unit provides an analytical framework for understanding power dynamics. Unit 3.2 explores how to build capacity for promoting more equitable distributions of power and well-being.

Preparation for class: To prepare for this Unit, please:

a) **Read**: Harley, A. G. (2025). *A framework for thinking about actors, institutions and power in nature-society systems*. Harvard University. (Available in Course Library)

b) **Read**: Harley, A., & Wexner, H. (2022). The Struggle for Sustainable Development in Appalachia's Mineral Rich Mountains. *Sustainability Science Program Working Paper*, *2022*(1), 65. and in the Course Library.

Study Questions to help you get the most out of the readings:

I. **Actors, Institutions, and Power:** In your own words, explain how the three dimensions of power differ from one another. Why might focusing only on visible, observable conflicts (first dimension) give us an incomplete picture of how power operates in nature-society systems? How do the three dimensions reinforce each other to maintain existing development pathways?

II. **Three Dimensions of Power in Appalachia between 1870 and 1920 :** Using the company town era described in Section 5 (pages 11-16) of the Appalachian case (reading 'b'), map the coal-based consumption-production system from extraction through consumption. Identify key actors at each stage and the institutional arrangements (both formal rules and informal norms) that governed their interactions. Then analyze how coal companies exercised all three dimensions of power to maintain control over this system. Provide specific examples for each dimension.

III. **Power Dynamics in Contemporary Appalachia:** How have the actors, institutions, and power dynamics evolved in contemporary Appalachia? Focus on current struggles over mountaintop removal mining and economic transition. Which dimensions of power are most important today? How do contemporary coal companies maintain influence despite declining employment and environmental opposition? What has changed since the company town era and what remains similar?

IV. **Your Case:** Apply our examination of actors, institutions, and power to a sustainability challenge you're studying. Identify the key actors and map which dimensions of power they exercise. Is the current distribution of power fostering or hindering efforts to promote a more equitable distribution of wealth and well-being within and among generations in your case?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

c) **Read**: Gaventa, J. (1980). *Power and Powerlessness: Quiescence and Rebellion in an Appalachian Valley*. University of Illinois Press.
This foundational text develops the three-dimensional framework of power through a detailed study of the same Appalachian coal region examined in our case study.

d) **Read**: Global Witness. (2023). *Standing firm: The Land and Environmental Defenders on the frontlines of the climate crisis*. https://globalwitness.org/en/campaigns/land-and-environmental-defenders/standing-firm/
Documents 177 environmental defenders killed in 2022 while protecting their community's land and resources, illustrating the most extreme form of compulsion through violence— the first dimension of power.

e) **Read**: Kashwan, P. (2017). Inequality, democracy, and the environment: A cross-national analysis. *Ecological Economics*, *131*, 139–151. https://doi.org/10.1016/j.ecolecon.2016.08.018
Analyzes how institutional arrangements in different political systems systematically exclude certain actors from environmental decision-making—second dimension of power in action.

f) **Read**: Supran, G., Rahmstorf, S., & Oreskes, N. (2023). Assessing ExxonMobil's global warming projections. *Science*, *379*(6628). https://doi.org/10.1126/science.abk0063
Documents how ExxonMobil's internal climate scientists accurately predicted global warming while the company publicly sowed doubt—quantitative evidence of the third dimension of power in action.

Unit 2.7 Inequality: How does inequality arise and persist in complex adaptive systems?

Rising inequality has emerged as a defining challenge of our era. After declining for much of the 20th century, within-country inequality has surged since 1980 in nearly all regions. Today, the richest 1% of the world's population owns nearly half of all global wealth, while the poorest half of humanity owns just 2%. This extreme inequality directly challenges the foundational vision of sustainable development—the commitment to equitable improvements in well-being both within and across generations.

Understanding the mechanisms that create and maintain inequality is essential for achieving the equity goals of sustainable development. Building on our analysis of actors, institutions, and power (Unit 2.6), we now examine how heterogeneity generates inequality among actors. Both theory and empirical evidence demonstrate that inequality is an emergent property of all complex adaptive systems. Even when everyone follows identical rules and starts with similar opportunities, inequality has a tendency to snowball—small differences in initial conditions compound through positive feedback loops such that wealth distributions become increasingly unequal over time.

Research identifies two key mechanisms that reinforce emergent inequalities. First, incumbent actors leverage their power across multiple dimensions—using resource control to compel others, shaping institutions to exclude challengers, and promoting narratives that naturalize hierarchy (as explored in Unit 2.6). This dynamic is intensified by what psychologists call social dominance orientation—some proportion of most populations actually prefer hierarchy to equality. Second, cultural processes reflect and reproduce inequality through narratives, norms, and beliefs that make existing distributions seem natural or inevitable. Together, these mechanisms transform what might begin as small, random differences into entrenched patterns of inequality that persist across generations. This unit explores how the heterogeneity of complex adaptive systems naturally tends toward unequal distributions and examines the self-reinforcing dynamics that make inequality so persistent. While the dynamics explored here reveal formidable challenges, Unit 3.2 examines capacities for promoting equity, including institutional reforms, social movements, and empowerment strategies that have successfully countered these self-reinforcing inequalities.

Preparation for class: To prepare for this unit, please:

a) **Explore**: Hasell, J., Rohenkohl, B., Arriagada, P., Ortiz-Ospina, E., & Roser, M. (2023). Economic Inequality. *Our World in Data*. https://ourworldindata.org/economic-inequality
Interactive visualizations and analysis of how global income and wealth inequality have evolved over time.

b) **Read and Explore:** Return to the NetLogo guide you first explored in Unit 2.2 on Stocks and Flows (i.e. Clark, W. C., & Harley, A. G. (2025). *NetLogo Guide for Sustainable Development Course*. Harvard University. (available in the Course Library). Review Section 1 “Basic access” and explore Section 5 “NetLogo wealth distribution model.”

c) **Read**: Milanovic, B. (2024). The three eras of global inequality, 1820–2020 with the focus on the past thirty years. *World Development*, *177*, 106516. https://doi.org/10.1016/j.worlddev.2023.106516

d) **Read:** Scheffer, M., van Bavel, B., van de Leemput, I. A., & van Nes, E. H. (2017). Inequality in nature and society. *Proceedings of the National Academy of Sciences*, *114*(50), 13154–13157. https://doi.org/10.1073/pnas.1706412114
Empirical evidence that inequality is a fundamental pattern in both natural and social systems.

Study Questions to help you get the most out of the readings:

I. **Exploring Trends in Inequality**: Explore how inequality differs within versus between countries using the **Our World in Data** section on Economic Inequality (reading 'a'). What has happened to global inequality over the past 40 years when we look at individuals regardless of country? How does this differ from inequality trends within countries? What patterns surprise you?

II. **Emergence from heterogeneity**: Exploring the Netlogo Wealth Distribution Exercise (reading 'b'), test at least two of the sources of heterogeneity presented there. How much does introducing those heterogeneities change the inequality of wealth distribution that is produced as an outcome of the model? (Think about outcomes in terms of the Gini Index). How much inequality emerges from small differences? What happens when you add inheritance? Explain how positive (reinforcing) feedback loops turn small initial differences into large inequalities. How might the simplified assumptions in this model differ from real-world dynamics where actors have varying degrees of power (as explored in Unit 2.6)?

III. **Historical patterns**: What are the three major eras of global inequality Milanovic identifies in reading 'c'? How do his findings relate to what you observed in the *Our World in Data* visualizations? What forces drive the shift from declining to rising within-country inequality after 1980?

IV. **Inequality as system property:** How does Scheffer et al.'s evidence from natural systems (reading 'd') help explain the patterns you observed in the NetLogo model? What does it mean that inequality appears across both natural and social systems for our efforts to promote equity?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

e) **Read**: Milfont, T. L., Bain, P. G., Kashima, Y., Corral-Verdugo, V., Pasquali, C., Johansson, L.-O., Guan, Y., Gouveia, V. V., Garðarsdóttir, R. B., Doron, G., Bilewicz, M., Utsugi, A., Aragones, J. I., Steg, L., Soland, M., Park, J., Otto, S., Demarque, C., Wagner, C., … Einarsdóttir, G. (2018). On the relation between social dominance orientation and environmentalism: A 25-nation study. *Social Psychological and Personality Science*, *9*(7), 802–814. https://doi.org/10.1177/1948550617722832
Academic research showing that more unequal societies tend to value environmental protection less than more equal societies, revealing links between psychological preferences for hierarchy and sustainability challenges.

f) **Read**: Bennett, H. (2017, November 2). Have psychologists found a better way to persuade people to save the planet? *The Guardian*. https://www.theguardian.com/inequality/2017/nov/02/psychologists-better-way-persuade-people-to-save-planet-environment
Accessible introduction to social dominance theory and its implications for sustainability.

g) **Read**: Chancel, L. (2020). *Unsustainable inequalities: Social justice and the environment*. The Belknap Press of Harvard University Press.
Book-length analysis explicitly connecting inequality to environmental challenges and sustainability—showing how social and ecological inequalities reinforce each other.

h) **Read:** Zucman, G. (2019). Global wealth inequality. *Annual Review of Economics*, *11*(1), 109–138. https://doi.org/10.1146/annurev-economics-080218-025852
Accessible review article synthesizing research on wealth inequality patterns and mechanisms globally.

Unit 2.8 Synthesis: How do interactions among the elements and relationships of nature-society systems shape pathways of development in the Anthropocene?

In Unit 1.1, we introduced a simple framework for analyzing nature-society systems. Throughout the rest of Part I of the course, we've explored individual elements of this simple framework in detail: goals for sustainable development (1.2) and resources that constitute the productive base that people can draw on to achieve those goals (1.3-1.5). In Part 2 of the course, we moved beyond this simple framework, exploring system dynamics including stocks and flows (2.1-2.2), nonlinearities and tipping points (2.3), horizontal connections linking places (2.4), vertical connections across levels (2.5), and actors with their institutions and power (2.6). In this unit, we will synthesize the concepts we have studied in part 2 of the course into a more complex version of the framework we introduced in Unit 1.1. This (evolving) framework is **not** meant to predict outcomes or serve as a grand theory of everything, rather it highlights what researchers have found useful to examine when studying how nature-society interactions unfold in different contexts. In other words, we use the framework as a helpful 'checklist' of elements and relationships worth considering when analyzing nature-society interactions—a first step to asking how we might transform nature-society systems onto more sustainable development pathways (something we will turn to in Part 3 of the course).

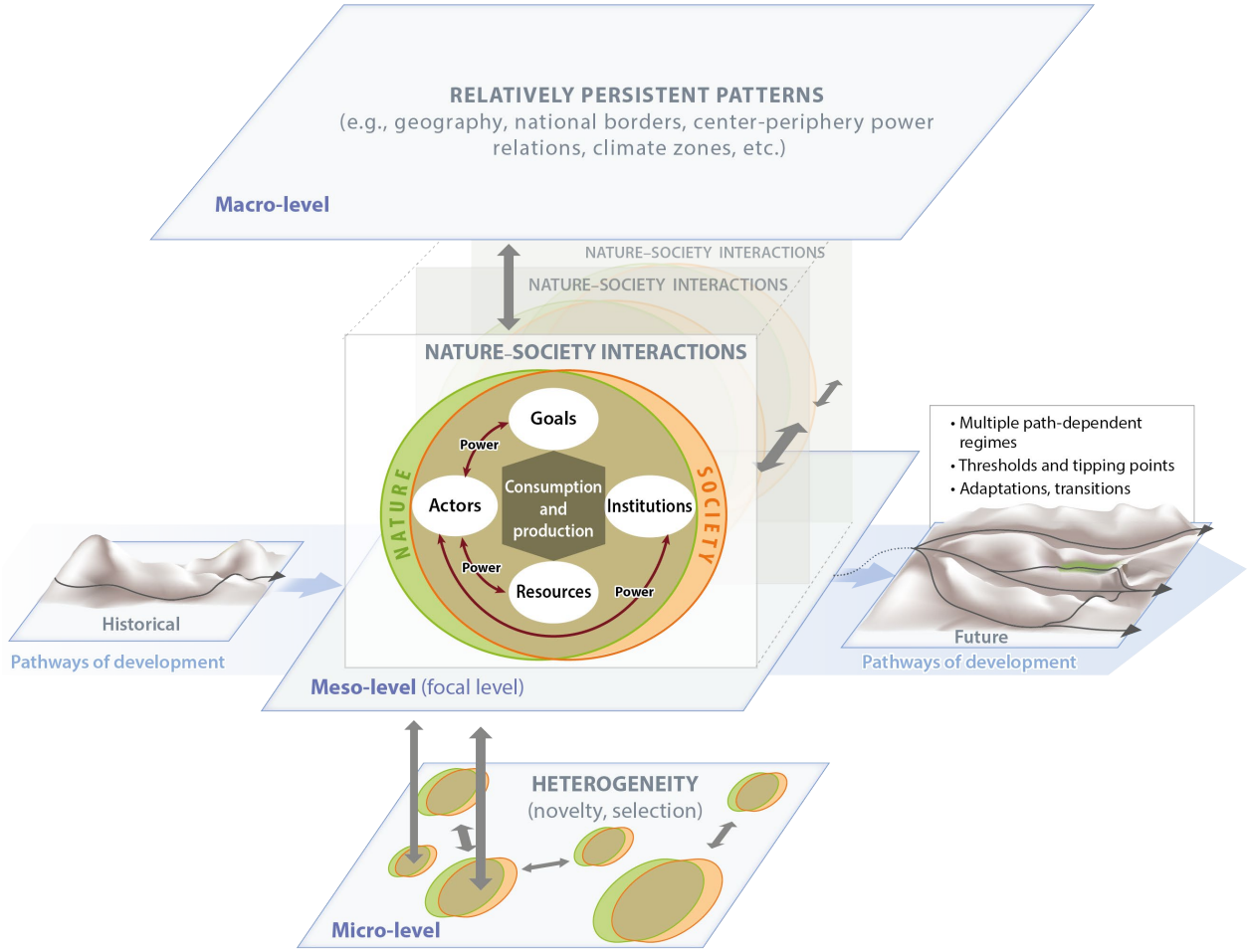

Figure 2: Framework for Research in Sustainability Science. From Clark and Harley (2020). Annual Review of Environment and Resources.

The framework (Figure 1 above) is developed in detail in reading 'a' of this Unit and summarized here. At the center of the figure are the intertwined nature-society interactions* we first encountered in Unit 1.1. The framework identifies four key elements involved in those interactions: goals (what people want from sustainable development), resources (the capital assets that may be natural or anthropogenic), actors (communities, firms, states and other entities with agency that strive to use resources to achieve their goals), and institutions (rules, norms, culture, beliefs that shape the behavior of actors). These elements are bound together through relationships of consumption and production, mediated by the relative power of different actor groups to affect one another's actions and beliefs (Unit 2.6). These elements and relationships generate emergent properties including the tendency toward inequality (Unit 2.7)—a pattern that appears across both natural and social systems and shapes how resources, power, and well-being are distributed among actors.

Context dependence is emphasized in the figure through multiple sets of nature-society systems that are always in play (shown by the multiple ovals in the figure's center), each with its own variants of goals, resources, actors, and institutions connected through production and consumption and mediated by power. The framework underscores the importance of being both specific about the particular nature-society interactions being studied (often called an 'action situation' or 'focal case' in the literature), while keeping in mind other potentially relevant nature-society systems and the potential horizontal connections among them (e.g., transboundary pollution, spill-over of local discoveries, migration, trade).

Nature-society interactions constitute a complex adaptive system, resulting in an emergent hierarchical structure, pictured here in terms of meso-, macro-, and micro-levels of organization. Lower (micro) levels highlight the heterogeneity (diversity) of elements often treated as aggregates at higher levels. While higher levels (macro) are often treated as immutable forces (e.g. governance arrangements, weather patterns) acting on the focal nature-society interactions of interest. This hierarchical character is why connections are such a focus of sustainability research: horizontal connections within levels, but also vertical connections between micro- and meso-levels (e.g., innovation) and between meso- and macro-levels (e.g., climate change, war).

The pathways of development emerging from these elements and relationships are strongly path dependent, exhibiting multiple regimes (valleys in the figure) separated by thresholds or tipping points (ridges). Adaptation keeps development pathways within their original regimes in the face of shocks. More rarely, transformation from one regime to another can occur due to changes in the underlying landscape or due to emergence of new technologies or social movements that challenge existing path dependence. Transformational changes can falter if they fail to cross into a new stable regime, precipitating development back into its original regime (see the trajectory running through the "green meadow" in the figure's future pathway).

Preparation for class: To prepare for this unit, please:

a) **Read**: Clark, W. C., & Harley, A. G. (2020). Sustainability Science: Toward a Synthesis. *Annual Review of Environment and Resources*, *45*, 331–386. https://doi.org/10.1146/annurev-environ-012420-043621

In this review paper we detail our Framework for Research in Sustainability Science (figure 1 above). For this unit, please read pages 331-342 in detail as they are foundational to synthesizing what you have learned thus far in this course and will prepare you well for moving forward into Part 3 of the course. We will read the rest of the paper in the next Unit as we begin to explore the capacities necessary to shift nature-society systems from unsustainable to sustainable pathways of development.

* Terminology note: As you have seen already, you will encounter various terms for these intertwined systems throughout the literature—"social-environmental systems" (as used in the Matson et al. 2016 book), "nature-society systems" (as we use here and in the readings for today), "social-ecological systems" (common in resilience literature), and sometimes "coupled human-natural systems." These all refer to the same basic concept: the integrated systems formed by the co-evolution of human societies and the natural environment.

b) **Watch**: Clark, W. C., & Harley, A. G. (2020). Framework for Research in Sustainability Science (video presentation 15 mins). In National Academies of Sciences, Engineering and Medicine (Ed.), *Progress Challenges and Opportunities for Sustainability Science A Workshop* (p. 15 mins.). National Academies of Science (USA). https://scholar.harvard.edu/files/wclark/files/framework_for_research_in_sustainability_science_nas.mp4.

This video provides an overview of the Framework for Research in Sustainability Science introduced in reading 'a' above. It was recorded as part of the introduction to a workshop on sustainability science held by the National Academy of Sciences. The slides used in the presentation are available here.

c) **Review as needed**: Case study for the Alaska Salmon Fishery introduced in Unit 1.1: Thompson, M. (2021). *The Alaskan Salmon Fishery: Managing Resources in a Globalizing World*. Harvard University. (available in the Course Library).

Study Questions to help you get the most out of the readings:

I. **Nature-society interactions and system dynamics:** In Unit 1.1, you identified basic nature-society interactions in the Alaska salmon fishery case. Now, with your understanding of system dynamics: What are the key reinforcing feedback loops that have driven boom-bust cycles? What balancing feedbacks have helped stabilize the system since the 1970s? Identify a potential tipping point and early warning signals that might indicate the system is approaching this threshold.

II. **Resources, connections, and flows:** How have stocks of key resources (natural and anthropogenic) in the Alaska fishery changed over time? Trace how horizontal connections link Alaska's salmon to global markets and how vertical connections allow local innovations (like hatchery systems) to scale up. Why did some innovations spread system-wide while others (like fish traps) were abandoned?

III. **Power, actors, and institutions:** How do power relationships between processors, fishers, regulators, and Native communities shape production decisions and governance? How have these dynamics changed from the cannery era to today's limited entry system? How do institutions like the limited entry permit system, escapement-based management, and fishing technology regulations (such as the ban on fish traps and gear restrictions) actually function to mediate between different actors' interests and constrain or enable their actions?

IV. **Inequality in the fishery:** Building on your analysis of power dynamics above, how do these relationships create and maintain inequalities in the distribution of benefits from the fishery? Which groups have gained or lost access to resources over time, and how have institutional changes either reduced or reinforced these inequalities?

V. **Comprehensive sustainability assessment:** Drawing on the inclusive wealth framework (Unit 1.5) and system dynamics: a. Assess whether the Alaskan salmon fishery's current trajectory is sustainable, considering the full portfolio of capital assets b. How do threshold effects and path dependencies determine whether consumption is "too much"? c. How might climate-driven shifts affect different communities' inclusive wealth differently?

VI. **Path dependence and thresholds:** How has Alaska's history created path dependencies that constrain current options (consider the legacy of cannery infrastructure, limited entry permits, established fishing communities)? What forces keep the fishery operating within its current regime despite various shocks? What combination of pressures might push the system across a threshold into a fundamentally different state - and what might that alternative state look like?

VII. **Your own case:** Apply this integrated framework to a sustainability challenge you're familiar with, identifying key feedbacks, important connections (horizontal and vertical), path dependencies and thresholds, and potential interventions that might shift your case toward sustainability.

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

d) Meyfroidt, P., Roy Chowdhury, R., de Bremond, A., Ellis, E. C., Erb, K.-H., Filatova, T., Garrett, R. D., Grove, J. M., Heinimann, A., Kuemmerle, T., Kull, C. A., Lambin, E. F., Landon, Y., le Polain de Waroux, Y., Messerli, P., Müller, D., Nielsen, J. Ø., Peterson, G. D., Rodriguez García, V., … Verburg, P. H. (2018). Middle-range theories of land system change. *Global Environmental Change*, *53*, 52–67. https://doi.org/10.1016/j.gloenvcha.2018.08.006

Both of the 'digging deeper' papers assigned for this unit address deep questions of the use theories and frameworks in sustainability science. They are meant for students wishing to reflect not just on the synthetic farmwork we present here, but also on broader questions of types of theories and frameworks that are useful for those interested in furthering the cause of sustainable development. The first paper by Meyfroidt et al. explores how to develop theories that bridge highly context-dependent cases and universal principles—a central challenge in applying frameworks to real-world sustainability problems. The authors discuss different approaches to theorizing about nature-society systems at intermediate levels of abstraction.

e) Schlüter, M., Caniglia, G., Orach, K., Bodin, Ö., Magliocca, N., Meyfroidt, P., & Reyers, B. (2022). Why care about theories? Innovative ways of theorizing in sustainability science. *Current Opinion in Environmental Sustainability*, *54*, 101154. https://doi.org/10.1016/j.cosust.2022.101154

The second paper by Schlüter et al. examines how different research approaches—from frameworks to models to empirical studies—can be integrated to better understand the complex causal relationships in nature-society systems. It provides valuable perspective on how the framework presented in this unit relates to other tools for sustainability analysis.

Unit 3.1 Capacities for sustainable development: What capacities are needed to guide development pathways toward sustainability?

Having explored the conceptual foundations of sustainable development in Part I of this course and examined the properties of the Anthropocene as a complex adaptive system in Part II, we now turn to the practical question of implementation. The pursuit of sustainability is not simply a matter of understanding problems or setting good intentions. It requires the ability to get things done—to connect widespread agreement on the goals of sustainable development with effective action. Yet too often societies fail to act at the speed and scale that many sustainability challenges require. This is at least in part because traditional approaches focus on understanding problems rather than building the practical capacity to act in contexts of uncertainty, competing interests, and inevitable surprises. This unit introduces Part III of the course by asking a fundamental question: What strategic capacities do advocates for sustainable development need in order to successfully guide development pathways toward sustainability?

As discussed in Part II, development pathways in nature-society systems are complex, characterized by nonlinear dynamics, tipping points, path dependence, multi-scale interactions and actors with agency and power. Given these properties, science has substantial ability to understand, but limited ability to predict, how long term development pathways will actually unfold. This means that interventions intended to promote sustainable development cannot be engineered from the top down or fully mapped out in advance. Instead, they must emerge through adaptive processes that combine the best available knowledge with ongoing experimentation and learning from both successes and failures. Moreover, pursuing sustainability requires continuous 'everyday' work—monitoring, adjusting, coordinating—undertaken by diverse actors working across a wide range of contexts. The challenge is how these actors, whether individuals, communities, organizations or states, can prepare for and carry out the ongoing work of fostering sustainable development.

One approach to this challenge that has emerged in recent years focuses on building and maintaining capacities for sustainable development. By capacity we mean both the intention and the ability to accomplish a task or achieve an outcome or, more bluntly, "the ability to get stuff done." This capacity-building approach represents a fundamental shift from asking ‘What’s to be done?’ to ‘How can people build and maintain the collective ability to figure out what to do and then to actually do it?’

Research over the past two decades has identified six strategic capacities that appear essential for the successful pursuit of sustainability: the capacity to measure progress, the capacity to promote equity, the capacity to adapt to shocks and surprises, the capacity to transform unsustainable development pathways, the capacity to link knowledge with action, and the capacity to devise governance arrangements that enable people to work together in exercising the other capacities (see figure 1). The next 6 units focus on what is known from both research and practice about each of these six capacities.

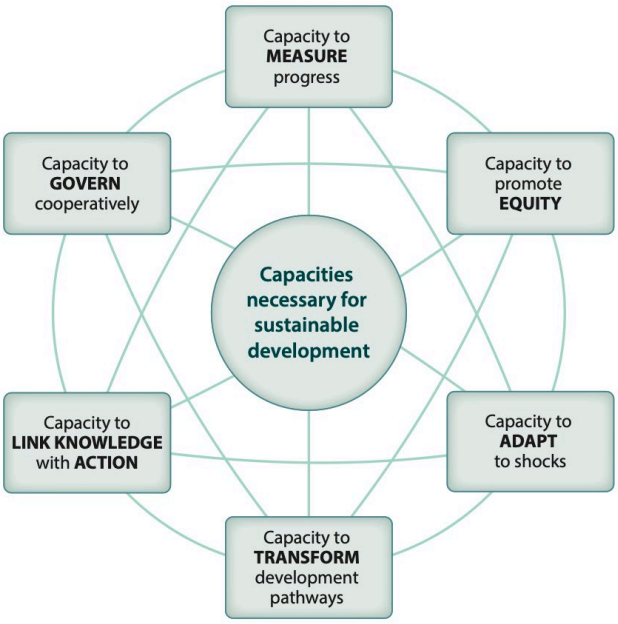

Figure 3: Six Capacities Necessary for Sustainable Development (Clark and Harley, 2020)

Preparation for class: To prepare for this Unit, please:

a) **Read**: Clark, W. C., & Harley, A. G. (2020). Sustainability Science: Toward a Synthesis. *Annual Review of Environment and Resources*, *45*(1), 331–386. https://doi.org/10.1146/annurev-environ-012420-043621

This review synthesizes two decades of sustainability science research and introduces the six-capacities framework that structures Part III of this course. You began this paper in Unit 2.8, where you read pages 331-342 covering the Framework for Research in Sustainability Science. Now complete the paper by reading pages 343-372, which detail the six capacities for sustainable development that will guide Part III of this course.

b) **Read**: Sen, A. (2000). *Development as Freedom* (1st Anchor Books ed.). Anchor Books.

This foundational work introduces Amartya Sen's influential "capabilities" approach, which focuses on expanding individual human capabilities and freedoms. While you read reflect on the differences between how Sen conceptualizes capabilities and how capacities are conceptualized in the readings for this unit.

c) **Explore**: United Nations Department of Economic and Social Affairs. (n.d.). *Capacity Development*. Retrieved December 20, 2024, from https://sdgs.un.org/topics/capacity-development

Study Questions to help you get the most out of the readings:

I. **Capacities as a collective endeavor**: Sen's capabilities approach (reading 'b') focuses on expanding individual freedoms and capabilities (what people can actually do and be), while the six-capacities framework (reading 'a') focuses on collective capacities that societies need to navigate toward sustainability. How do these two approaches relate to each other?

II. **Global perspectives on capacity development**: How does the UN conceptualize "capacity development" (reading 'c') compared to the six-capacities framework presented in Clark & Harley (reading 'a')? What assumptions does each approach make about who needs capacity, who builds it, and how it develops? What are the strengths and limitations of each approach?

III. **Building capacities**: The place-based nature of sustainability challenges discussed in Clark & Harley (reading 'a') means that these capacities must be built by "diverse communities" working together "across places and time." What does this suggest about the scale and scope of capacity building efforts? What are the implications for how we think about sustainability as a collective endeavor?

IV. **Capacity trade-offs and tensions**: Reading 'a' emphasizes that the six capacities are interdependent—they often function as complements but can also exist in tension with one another. Can you think of examples where building one capacity might conflict with building another? How might practitioners navigate such trade-offs?

V. **Capacities in Appalachia:** Reflecting on the Appalachia case assigned earlier in the course in Unit 2.6: Given the region's history of resource extraction, power imbalances, and community resistance movements, which of the six capacities are most needed to be strengthened by local actors to better foster sustainable development in the region today? Explain your reasoning.

VI. **Your own case:** Consider a sustainability challenge you're familiar with (it could be from your hometown, a case study from earlier in this course, or current events). Which of the six capacities seem most relevant to addressing that challenge? Which of the capacities seem least developed among the relevant actors?

Digging deeper (optional materials for further exploring a broad perspective on capacity building):

d) Read: Mazzucato, M., & Kattel, R. (2020). COVID-19 and public-sector capacity. *Oxford Review of Economic Policy*, *36*(Supplement_1), S256–S269. https://doi.org/10.1093/oxrep/graa031
This reading looks at the capabilities and capacities that were too often missing from governments' responses to the outbreak of the COVID-19 pandemic. The capacities it focuses on (capacity to adapt and learn; capacity to align public services and citizen needs; capacity to govern resilient production systems; and capacity to govern data and digital platforms) are slightly different from the six capacities we will highlight in Part III of this course. Nevertheless, it is a powerful argument about the importance of capacities in our collective ability to respond to shocks and surprises—a theme central to our understanding of managing under deep uncertainty.

Unit 3.2 Capacity to Promote Equity: How can we promote equitable distribution of the fruits of the earth's resources within and between generations?

Equity —the fair distribution of resources within and between generations—stands at the heart of sustainable development. The Brundtland Commission made this clear in 1987, and subsequent international deliberations have reaffirmed this perspective: alleviating poverty among today's most vulnerable while ensuring that efforts to improve well-being today do not undermine the prospects of those seeking it tomorrow.

Yet despite these normative commitments, the equity dimension of sustainability is often strangely neglected in practice. One need look no further than the UN SDGs for evidence of this neglect—while the preamble acknowledges "present and future generations," none of the 17 SDGs explicitly addresses intergenerational equity. This gap between aspiration and action becomes less surprising when we consider what you've learned in Units 2.6 and 2.7: power concentrates in the hands of incumbent actors who benefit from existing inequalities, while inequality itself emerges as a natural tendency in complex systems, reinforced by positive feedback loops that make the rich get richer and the poor get poorer.

In this unit, we explore what research tells us about building a stronger capacity to promote equity both within and between generations—not just as a moral imperative, but as a strategic necessity for sustainable development. Building on your understanding of how power creates and maintains inequality, we now turn to the practical question: How can actors develop the capacity to counter those dynamics and to instead foster more equitable distributions of well-being?

Building capacity to promote equity requires more than good intentions or moral commitments. It demands strategic action that confronts power across all its dimensions. As John Gaventa argues in his classic study of power in Appalachian coal country (reading 'd' from Unit 2.6), the three dimensions of power can also reveal pathways to empowerment. Just as powerful actors use resources to compel (first dimension), institutions to exclude (second dimension), and narratives to influence (third dimension), movements for equity must develop countervailing strategies across all three dimensions. The framework below (adapted from Gaventa 1980) illustrates how each dimension of powerlessness points toward specific empowerment strategies.

This framework (see figure 1) reveals that building capacity to promote equity involves three interconnected strategies:

1. **Issue and action formation (countering the third dimension):** Developing critical consciousness about structural inequities and the narratives that naturalize them; formulating alternative visions and strategies for change.
2. **Mobilization upon barriers (countering the second dimension):** Identifying and dismantling institutional barriers that exclude marginalized actors from decision-making; creating new spaces for participation.
3. **Resource mobilization (countering the first dimension):** Building coalitions and marshaling resources to contest decisions in open arenas; developing the organizational capacity for sustained collective action.

Figure 4: The Three Dimensions of Power and Empowerment (Adapted from Gaventa, 1980, p. 21)

These strategies have proven effective across diverse contexts. Movements have successfully shifted narratives from GDP growth to wellbeing and SDGs (countering third dimension influence), placed climate change and sustainability on policy agendas that previously ignored them (countering second dimension exclusion), and enabled indigenous communities to reclaim ancestral lands and establish marine protected areas (countering first dimension compulsion). Each victory demonstrates that the same dimensions of power used to maintain inequality can be redirected toward equity. That said, such victories have been far from universal or irreversible. Capacity building to promote equity must persistently address two distinct but related equity challenges. **Intra-generational equity** requires redistributing resources and opportunities among today's actors—a challenge complicated by the self-reinforcing dynamics of inequality explored in Unit 2.7. **Intergenerational equity** demands protecting resources and opportunities for future generations who cannot advocate for themselves in today's decision-making. The same power imbalances that create inequality within generations also determine whose voices shape decisions about the future. This continues to result in development pathways that discount both the needs of today's marginalized communities and tomorrow's generations.

Preparation for class: To prepare for the class, please:

a) **Read**: Hoen, E. 't, Berger, J., Calmy, A., & Moon, S. (2011). Driving a decade of change: HIV/AIDS, patents and access to medicines for all. *Journal of the International AIDS Society*, *14*, 15. https://doi.org/10.1186/1758-2652-14-15

Documents how activists and NGOs successfully confronted pharmaceutical industry power to ensure access to life-saving HIV/AIDS medicines in developing countries, demonstrating effective empowerment strategies in action.

b) **Explore:** Our Children's Trust. (n.d.). *Juliana v. United States*. Retrieved October 12, 2025, from https://www.ourchildrenstrust.org/juliana-v-us

Review this landmark youth climate litigation case as an example of innovative strategies to promote intergenerational equity through legal mechanisms that give voice to future generations' interest.

c) Review: Harley, A., & Wexner, H. (2022). The Struggle for Sustainable Development in Appalachia's Mineral Rich Mountains. *Sustainability Science Program Working Paper*, *2022*(1), 65. (Available in Course Library). Read Sections 10-11 (pages 34-47), focusing on how citizen activism confronted the three dimensions of coal company power.

Building on your analysis of power in Appalachia (Unit 2.6), these sections examine how marginalized communities have employed empowerment strategies to challenge entrenched interests, from the Pittston strike to contemporary environmental justice movements.

Study Questions to help you get the most out of the readings:

I. **From power analysis to strategies for empowerment:** Using the Gaventa framework presented in this unit, identify specific examples from Sections 10-11 of the Appalachian case (reading 'c') where marginalized actors successfully employed each of the three empowerment strategies (issue and action formation, mobilization against barriers, and resource mobilization). Which dimension of power was hardest to counter effectively and why?

II. **Empowering marginalized voices within and between generations:** Compare the strategies of empowerment used in the HIV/AIDS campaign (reading 'a') with the legal approach in the Juliana case (reading 'b'). How do these different mechanisms work to ensure those without power are heard in current decision-making? What are their strengths and limitations?

III. **Your case:** Apply the three-dimensional empowerment framework from this unit to a marginalized group in your chosen sustainability challenge. Design a comprehensive strategy that addresses all three dimensions of power. What resources, alliances, and institutional changes would be needed? What barriers would be most difficult to overcome?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

d) Read: Harley, A. G., & Clark, W. C. (2025). *Building Capacity to Promote Equity with and among Generations: Lessons from scholarship and practice* (Nos. 25–04; Sustainability Science Program Working Paper, pp. 1–19). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Equity%20Capacity_SSP%20Working%20Paper.pdf (Available in Course Library)

This working paper provides important background on equity-building strategies across different contexts globally. While academic in style, it offers a useful synthesis of lessons from practice that will inform your analysis of the specific cases.

e) Read: Chenoweth, E. (2021). *Civil resistance: What everyone needs to know*. Oxford University Press.

Analyzes what makes social movements succeed or fail, with implications for building sustained capacity for equity promotion through collective action.

f) Read: Boston, J. (2017). *Governing for the Future: Designing Democratic Institutions for a Better Tomorrow* (First edition). Emerald.

Examines how democratic institutions can be designed to protect future generations' interests, addressing the challenge of "presentist bias" in policy-making and proposing concrete mechanisms for intergenerational equity.

g) Explore: Sabin Center for Climate Change Law, Columbia Univ. (n.d.). *The Climate Litigation Database*. Retrieved October 12, 2025, from https://www.climatecasechart.com

For students interested in exploring the wider landscape of climate litigation beyond youth cases, the Sabin Center maintains comprehensive databases tracking over 3,000 climate cases worldwide, including constitutional and human rights cases that address intergenerational equity through various legal strategies.

Unit 3.3 Capacity to Measure Progress: What do we know from science and practice about what is needed to measure progress toward sustainability?

How sustainable development is measured inevitably guides how societies pursue their sustainability goals, yet building coherent measurement systems has proven to be one of the field's most persistent challenges. While the overarching goals of sustainable development have been clearly articulated since the 1980s, conceptually coherent measurement systems for tracking progress toward those goals have lagged significantly behind. This Unit explores what sustainability science has learned about measuring sustainable development—both the conceptual foundations for measurement and the practical challenges of building measurement capacity at scale. Such capacity is essential not only for tracking whether we're making progress, but also for use in evaluating whether proposed interventions are likely to foster sustainable development, signaling when improvements in one context come at the expense of others, and providing a basis for negotiation when sustainability challenges cross boundaries of space and time.

Encouragingly, the past two decades have seen substantial advancements in building the capacity to measure progress toward sustainability. Scholars have refined and deepened our understanding of meaningful measurement systems. And national governments, international organizations, civil society, and the private sector are developing practical approaches—from inclusive wealth accounting to multi-dimensional dashboards—that move beyond theory to inform real-world decisions. While building a mature capacity to measure sustainability remains a work in progress, the field is advancing rapidly.

Building on the theoretical foundations of inclusive wealth introduced in Unit 1.5, we now turn from retrospective to prospective analysis. In Unit 1.5, we addressed retrospective sustainability assessments, evaluating whether recent and current development trends are sustainable by asking questions like "Are the prospects people have today for improving their lives and the lives of their descendants better now than they were a generation ago?". In this unit, we shift to prospective analysis—the capacity to measure and evaluate whether particular interventions would be likely to promote improvements in the pursuit of sustainability. We address questions such as "How would alternative land-use decisions affect the provision of ecosystem services and human well-being?". We will also look at what sustainability leaders are doing around the world to build a more robust capacity to measure progress toward sustainability in practice.

Preparation for class: To prepare for this Unit, please:

a) **Read**: Harley, A. G., & Clark, W. C. (2025). *Building Capacity to Measure Sustainability: Lessons from scholarship and practice* (Nos. 25–01; Sustainability Science Program Working Paper, p. 18). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Measurement%20Capacity_SSP%20Working%20Paper.pdf (Available in Course Library)

This working paper synthesizes lessons from both scholarship and practice about what's needed to build and maintain a strategic capacity to measure sustainability, including insights from cutting-edge efforts in countries (New Zealand) and organizations (the Natural Capital Project).

b) **Read**: OECD. (2020). *How's Life? 2020: Measuring Well-being*. OECD. https://doi.org/10.1787/9870c393-en. Read Chapter 2: "Conceptual Framework for Measuring Well-being and Progress" (pp. 31-52).

Building on the OECD Better Life Index you explored in Unit 1.2, this chapter presents the OECD's comprehensive framework now being used by multiple countries. It distinguishes between measuring current well-being (the constituents) and the resources needed to sustain it over time (the determinants). Pay special attention to how the authors handle the balance between current and future well-being, which directly relates to our shift from retrospective to prospective analysis.

c) **Explore**: World Bank. (2024). *The Changing Wealth of Nations 2024: Revisiting the Measurement of comprehensive wealth* (No. 193950). World Bank Group. http://documents.worldbank.org/curated/en/099100824155021548. Focus on the Executive Summary (available by scrolling down on this site) and explore this interactive data platform: https://datanalytics.worldbank.org/cwon/.

This report represents one of the most comprehensive efforts to date to measure inclusive wealth across countries and is the most recent comprehensive wealth accounting report in this series (the data platform is updated more frequently with new data points). Pay particular attention to how they value different types of capital assets.

d) **Read**: Goldstein, J. H., Caldarone, G., Duarte, T. K., Ennaanay, D., Hannahs, N., Mendoza, G., Polasky, S., Wolny, S., & Daily, G. C. (2012). Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(19), 7565–7570. https://doi.org/10.1073/pnas.1201040109

This paper demonstrates how natural capital measurement can inform real-world decision-making without necessarily monetizing all assets, instead providing multiple measures and tradeoffs that citizens can use in deliberating over their choices.

e) **Review**: Return to the London teaching case from Unit 1.4, i.e. Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. “London: The struggle for sustainable development in an urban environment” (pp. 143-165).

Study Questions to help you get the most out of the readings:

I. Design a measurement system for use in evaluating whether development in Victorian London (circa 1850-1900) was sustainable. What are the most important specific metrics that you would ideally include in such a system. What are the principal challenges in going from that ideal list to a feasible one?

II. The OECD Better Life Index you explored in Unit 1.2 measured current well-being across 11 dimensions. This Unit’s OECD reading shows how this framework has been expanded to also track the resources needed to sustain future well-being. How does this two-pronged approach address the intergenerational equity concerns central to sustainable development? What challenges remain in moving from measuring current stocks to evaluating future interventions?

III. Both the Harley & Clark working paper (reading ‘a’) and the OECD framework (reading ‘b’) distinguish between measuring well-being outcomes directly (constituents) versus measuring the resource stocks that produce well-being (determinants). Choose a specific sustainability intervention or case you are interested in (e.g., urban green infrastructure, renewable energy transition, wetland restoration etc.) and explain what you would measure using each approach. What insights would each type of measurement provide for evaluating the intervention's likely success?

IV. The Goldstein et al. paper (reading ‘d’) consciously avoids monetizing all ecosystem services. What are the advantages and disadvantages of this approach compared to efforts to create a single "inclusive wealth" number? How might this choice affect the ability to evaluate prospective interventions?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

f) **Read**: Dasgupta, P. (2014). Measuring the wealth of nations. *Annual Review of Resource Economics*, *6*(1), 17–31. https://doi.org/10.1146/annurev-resource-100913-012358

This paper provides the theoretical foundations for inclusive wealth accounting, explaining why wealth (properly measured) is the appropriate metric for sustainability and how to value resources that aren't traded in markets.

g) **Read:** Stiglitz, J. E., Fitoussi, J.-P., & Durand, M. (2018). *Beyond GDP: Measuring What Counts for Economic and Social Performance*. OECD. https://doi.org/10.1787/9789264307292-en. Read Chapter 1 "The continued importance of the 'Beyond GDP' Agenda" (pp. 17-37).

This chapter traces the evolution of thinking about measuring societal progress beyond GDP, providing essential context for understanding current approaches to sustainability measurement. The authors explain why GDP alone is insufficient and outline the key dimensions that more comprehensive measurement systems should capture.

h) **Read**: Wagner, G., Anthoff, D., Cropper, M., Dietz, S., Gillingham, K. T., Groom, B., Kelleher, J. P., Moore, F. C., & Stock, J. H. (2021). Eight priorities for calculating the social cost of carbon. *Nature*, *590*(7847), Article 7847. https://doi.org/10.1038/d41586-021-00441-0

The debate over the "social cost of carbon" exemplifies the conceptual and ethical challenges of valuing long-term, large-scale sustainability challenges—particularly relevant for prospective analysis of climate interventions.

i) **Explore**: Capitals Approach. (n.d.). *Capitals Coalition*. Retrieved October 12, 2025, from https://capitalscoalition.org/capitals-approach/ . Review "The Capitals Approach" and one case study

This global coalition is working toward their 2035 ambition of ensuring that the majority of businesses, financial institutions and governments will include the value of natural capital, social capital and human capital in their decision-making.

j) **Watch**: Harley, Alicia G. (Director). (2025, February 12). *Capacity building to measure progress toward sustainable development* [Video recording]. M-RCBG_Harvard. https://www.youtube.com/watch?v=1cYCqBiBwgg.

This is part of the C4SD Seminar Series, Sustainability Science Program, Harvard Kennedy School. The seminar explores practical challenges and emerging solutions in building capacity to measure sustainable development, with examples from multiple contexts showing how measurement systems can guide action toward sustainability.

Unit 3.4 Capacity to Adapt: How can societies mobilize resources to cope with unexpected shocks and changing conditions?

Adaptation has long been an important focus of research and practice in sustainable development. We define it as the ability to keep a system operating within its current regime and thus on something like its current development pathway in the face of potentially disruptive change. This distinguishes adaptation from transformation (see Unit 3.7), which involves shifting a system into a fundamentally different regime. From a systems perspective, adaptation often involves strengthening feedbacks that are "dampening" or "balancing" to maintain stability, while transformation requires "reinforcing" or "amplifying" feedbacks that push toward new states.

Adaptive capacity matters because development pathways in the complex adaptive system of the Anthropocene cannot be fully predicted in advance or managed without encountering surprise and disruption. Pursuing sustainable development therefore requires both "thinking through" the implications of available options as best we can, and "acting out" development as an experiment—implementing promising approaches, observing results, and adapting course as needed. Yet two decades of research reveal that while adaptation is everywhere — actors continuously respond to change through feedback processes — adaptation that genuinely reduces vulnerability rather than merely shifting it elsewhere remains frustratingly rare.

The scholarship on adaptation has produced several robust findings. First, while "richer is safer"—wealthier communities have more resources to cope with disruption—this refers not just to financial wealth but to the full portfolio of natural and anthropogenic resources that societies draw on to create well-being. For successful adaptation, communities benefit not only from plentiful resources but also from the agency to mobilize them effectively. Second, heterogeneity can enhance adaptive capacity by creating options for compensation and learning from others, but only when connections are appropriately managed; too-tight coupling propagates shocks universally while power imbalances shift risks onto vulnerable groups. Third, non-linear dynamics impose fundamental limits on trial-and-error learning through tipping points, path dependencies, and irreversible changes. Fourth, actors systematically prioritize responses to immediate acute shocks over chronic stresses, a "short-termism" that too often leaves communities perpetually reactive. These findings help explain why adaptation efforts so often result in "maladaptation"—interventions that reproduce existing vulnerabilities, redistribute risks to more vulnerable populations, or create new sources of fragility. This unit explores what science and practice have taught us about building adaptive capacity that reduces rather than redistributes vulnerability, empowers rather than marginalizes local actors, and navigates inevitable tradeoffs between immediate needs and long-term sustainability.

Preparation for class: To prepare for this unit, please:

a) **Read**: Harley, A. G., & Clark, W. C. (2025). *Building Capacity to Adapt Development Pathways to Protect Human Well-being in the Face of Shocks: Lessons from scholarship and practice* (Nos. 25–02; Sustainability Science Program Working Paper, p. 20). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Adaptation%20Capacity_SSP%20Working%20Paper_FINAL.pdf (Available in Course Library)
This working paper synthesizes two decades of research and practice on building adaptive capacity, examining both why adaptation is essential for sustainability and why it has proven so difficult to do well.

b) **Read**: Eriksen, S., Schipper, E. L. F., Scoville-Simonds, M., Vincent, K., Adam, H. N., Brooks, N., Harding, B., Khatri, D., Lenaerts, L., Liverman, D., Mills-Novoa, M., Mosberg, M., Movik, S., Muok, B., Nightingale, A., Ojha, H., Sygna, L., Taylor, M., Vogel, C., & West, J. J. (2021). Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Development*, *141*, 105383. https://doi.org/10.1016/j.worlddev.2020.105383

This systematic review of adaptation interventions reveals the troubling frequency of maladaptation—cases where adaptation efforts fail to reduce or even increase vulnerability. As you read, consider what factors distinguish successful adaptation from maladaptation. Note that while this paper presents important critiques of current adaptation practice, scholars debate whether such critiques might inadvertently harm vulnerable populations by discouraging adaptation funding (see Schipper & Mukherji in the optional readings for a counterargument).

c) **Explore**: *Adaptation at Altitude: Solutions Portal*. (n.d.). Adaptation At Altitude. Retrieved October 12, 2025, from https://adaptationataltitude.org/solutionsportal/

Review 2-3 case studies of mountain communities adapting to climate change, selecting those with more comprehensive information (these will typically have longer descriptions, multiple sections covering implementation details, outcomes, and lessons learned). As you explore these cases, note what specific resources were mobilized, who led implementation versus who benefited, what barriers were encountered, and whether the interventions built long-term adaptive capacity or provided temporary relief.

d) Review: Return to the London teaching case from Unit 1.4, i.e. Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. “London: The struggle for sustainable development in an urban environment” (pp. 143-165).

<u>Study Questions to help you get the most out of the readings</u>:

I. **Adaptation and Vulnerability in London:** Reading ‘a’ emphasizes that adaptation often shifts risks from one group to another rather than reducing overall vulnerability. The London case from Unit 1.4 describes how the city responded to increasing stench and health concerns they associated with backyard cesspits by eventually requiring all households to connect to sewers that discharged into the Thames, effectively creating "a common cesspool for all of London." This shifted indoor pollution to outdoors and concentrated waste downstream. Using the four lessons from reading ‘a’ — addressing vulnerability drivers, empowering local actors, embedding across scales, and acknowledging tradeoffs—analyze how this "solution" exemplifies the problem of risk redistribution in adaptation. What would a more sustainability-oriented adaptive response have looked like?

II. **Evaluate real-world adaptation efforts:** Select two adaptation interventions from the Adaptation at Altitude Solutions Portal (reading ‘c’) that provide enough information to analyze their approach and outcomes. Analyze what these cases reveal about building adaptive capacity in practice. Consider both what the interventions achieved and what challenges they faced. How do these real-world efforts align with, diverge from, or extend beyond what the academic readings suggest about effective adaptation? What do these cases teach us that the scholarship might be missing? Where do they fall short, and what explains those shortcomings?

III. **Your case:** Design an adaptation strategy for a specific shock facing your case community (drought, flooding, heat waves, economic volatility, etc.). Create a brief assessment framework (3-4 key questions) to evaluate whether your intervention would genuinely build adaptive capacity or risk maladaptation. Focus particularly on: how to address root causes of vulnerability rather than just symptoms, and how to ensure local communities have real agency in the adaptation process.

<u>Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):</u>

e) **Explore**: *State and Trends in Adaptation: Report 2022*. (2022). Global Center on Adaptation. https://gca.org/reports/sta22/

Provides a comprehensive global assessment of current adaptation practices, financing gaps, and emerging trends, with particular focus on what's working and what's failing in vulnerable regions.

f) **Read:** Schipper, L., & Mukherji, A. (2024). Misguided negative adaptation narratives are hurting the poor. Science, 386(6722), 624–626. https://doi.org/10.1126/science.adq7821

This provocative commentary argues that academic findings about maladaptation are being weaponized to justify reducing adaptation funding, ultimately harming vulnerable populations. It offers an important counterpoint to the maladaptation literature, challenging readers to consider how critical research can be misused in policy contexts.

g) **Read**: Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources*, *32*(1), 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348

This comprehensive review synthesizes a large literature on how social-ecological systems respond to environmental change and remains foundational to contemporary adaptation scholarship.

h) **Read:** Kousky, C. (2019). The role of natural disaster insurance in recovery and risk reduction. *Annual Review of Resource Economics*, *11*(1), 399–418. https://doi.org/10.1146/annurev-resource-100518-094028

Examines how insurance mechanisms can both enable and constrain adaptation, exploring the tensions between using insurance for recovery versus risk reduction, and the challenges of making insurance work for vulnerable populations.

Unit 3.5 Capacity to Govern Cooperatively: How can we work together to achieve what we cannot achieve alone in the pursuit of sustainability?

Solving sustainability challenges requires diverse actors—often with competing interests and unequal power—to work together, often in the face of deep uncertainty and unexpected change. As we explored in Unit 2.6, governance emerges from the interactions among actors operating within institutional contexts, with power mediating their relationships. What distinguishes governance capacity from these raw elements is the deliberate effort to align these interactions toward collective goals—to create arrangements that enable cooperation despite divergent interests.

Sustainable development, as we saw in Part I of this course, is the name the world community has given to its collective goal of using the planet's resource commons to foster equitable improvements in human well-being, now and in the future. Garrett Hardin argued in his famous 1968 article (see supplementary reading 'b') that this goal could not be achieved through cooperation, claiming that "freedom in a commons brings ruin to all." Your own experience playing Fishbanks in Unit 0.2 might have suggested Hardin was right and that tragedies of the commons are inevitable. But decades of research have proven Hardin wrong. Humans have, on their better days, built the capacity to govern shared resources in ways that promote both intra- and inter-generational equity. This capacity doesn't emerge fully formed---it must be built incrementally, starting with small agreements between actors with divergent interests that can grow into increasingly robust and inclusive governance arrangements over time. As you'll see in the case studies cited in this course, successful governance requires discovering which roles different actors can play best, aligning their contributions to complement one another, and connecting strategies that foster collaboration from local to global levels.

We'll examine cases demonstrating governance at multiple scales, from local resource management in Nepal's irrigation systems to global cooperation on stratospheric ozone depletion. Both cases illustrate how actors working together have overcome collective action problems inherent in the goal of sustainable development.

Preparation for class: To prepare for this unit, please:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press.
- **Read:** "Governance in social-environmental systems," Ch. 4, pp. 83–104.
- **Read/Review**: The case study on "Farmer-managed irrigation systems in Nepal" (Appendix A, pp. 165–172).
- **Read/review:** The case study on "An international success story: Ozone and the Montreal Protocol" (Appendix A, pp.179–185, or search for the title).

Study Questions to help you get the most out of the readings:

I. **Returning to Fishbanks:** Garrett Hardin famously claimed that "freedom in a commons brings ruin to all" (see reading 'a' for brief overview and supplementary reading 'b' to read more about Hardin's perspective). In many ways, your own experience playing Fishbanks at the start of this course only served to underscore Hardin's assertion. But you stuck with this course presumably hopeful that sustainability science could teach you something that might help you and others better manage common pool resources and steer more sustainable development pathways going forward. So, if you were to play Fishbanks again, knowing what you know now from the course as a whole and from reading 'a' on governance in particular, what should you do differently? In particular, how would you design institutions to better manage your shared resources?

II. **Diagnosing Collective Action Problems:** Using Matson's analysis of governance processes in reading 'a', chapter 4, identify the specific collective action problems in each case (Farmer-managed

irrigation systems in Nepal and An international success story: Ozone and the Montreal Protocol). Which of the three barriers to collective action—motivational problems, power asymmetries, or information problems—were most significant in each case? Why?

III. **Understanding What Makes People Tick:** Matson chapter 4 emphasizes that "figuring out what makes people tick" is essential for governance. Compare how intrinsic versus extrinsic motivations played out differently across the two cases. Why did the "unusual bedfellows" alliance work in the ozone case? What motivated farmers in Nepal to cooperate despite individual incentives to defect?

IV. **Your Case:** Using the governance system framework discussed in reading 'a', map the 'Governance System' in your case. In particular, focus on:

Who are the groups of **actors** most central to promoting and/or impeding the pursuit of sustainability in the case? For each actor group, characterize which of its *interests* are most relevant—whether in a positive or negative way—to the pursuit of sustainability.

What **institutional arrangements** (rules, norms, culture, beliefs) are most important in shaping the prospects for sustainability in the case? In particular, what are the barriers and opportunities posed by these institutions for the pursuit of sustainability? When were these institutions put in place? Who had the greatest influence in shaping them? How have they been reshaped in ways relevant for sustainable development?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

b) Read: Hardin, G. (1968). The tragedy of the commons. *Science*, *162*, 1243–1248.

Influential paper arguing that multiple actors using a resource commons inevitably leads to overexploitation. Important historical context for understanding why Ostrom's work showing alternative pathways was so revolutionary.

c) **Read**: Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B., & Policansky, D. (1999). Revisiting the Commons: Local Lessons, Global Challenges. *Science*, *284*(5412), 278–282. https://doi.org/10.1126/science.284.5412.278.

Accessible overview of strategies for overcoming the 'tragedy of the commons' through collective management of common pool resources by Eleanor Ostrom (first female recipient of the Nobel Prize in Economics and one of the founders of sustainability science) and colleagues. Ostrom revolutionized our understanding of commons governance

d) **Read**: Dryzek, J. S. (2016). Institutions for the Anthropocene: Governance in a changing Earth system. *British Journal of Political Science*, *46*(4), 937–956. https://doi.org/10.1017/S0007123414000453.

This paper is an excellent overview of the challenges posed to governance by the complex, adaptive, multi-level character of the Anthropocene.

e) **Read:** Harley, A. G., & Clark, W. C. (2025). *Building Capacity to Govern Cooperatively in Pursuit of Sustainable Development: Lessons from scholarship and practice* (Nos. 25–06; Sustainability Science Program Working Paper, p. 20). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Governance%20Capacity_SSP%20Working%20Paper_Final.pdf (Available in Course Library).

This working paper synthesizes two decades of research and practice on building governance capacity, examining both why it is essential for sustainability and why it has proven so difficult to do well.

Unit 3.6 Capacity to Link Knowledge with Action: How can we ensure knowledge to support informed agitation for sustainability is utilized in practice?

Knowledge, we argued in Unit 1.3, is one of the key resources on which society draws to produce well-being. The stock of knowledge capital, like all resources, can be both depleted and augmented through human activities. Scholars and practitioners have built a growing stock of knowledge with the potential to inform action for sustainable development. Yet agitators working on the front lines of sustainability continue to lament the lack of action-oriented knowledge they most need. This gap between what is known about sustainable development and what is actually applied has long been recognized but remains stubbornly persistent.

The traditional model of science communication — where researchers produce knowledge and deliver it to users who are expected to act on it — has proven largely ineffective for sustainability challenges. This "loading dock" model fails because it ignores fundamental realities: knowledge and society continually shape each other in what scholars call co-production; actors will only use knowledge they trust; and trust emerges from collaborative processes that ensure knowledge is credible to users, salient to their needs and legitimate in their eyes.

Creating usable knowledge for sustainability requires recognizing it as simultaneously a collaborative enterprise (bringing together diverse expertise and perspectives), a systems enterprise (addressing interconnected problems across scales), an adaptive enterprise (learning and adjusting as conditions change), and a political enterprise (navigating power dynamics and incumbent interests). Boundary work—the processes through which research communities organize their relations with decision-makers and other knowledge holders—becomes essential for creating knowledge that can influence action.

In this unit, we explore how knowledge can be better linked with action to promote sustainable development. We examine why actors should let their actions be changed by the incomplete, contested knowledge that characterizes sustainability issues. We investigate the roles of co-production, trust, and boundary organizations in creating influential knowledge. And we consider how power shapes whose knowledge counts and how knowledge itself can become a tool for challenging or reinforcing existing development pathways.

Preparation for class: To prepare for this Unit, please:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press..
- **Read**: "Linking knowledge with action," Ch. 5, pp. 105–128.
- **Read:** The case study "The Yaqui Valley: Moving toward sustainability with imperfect but persistent interdisciplinary research" Appendix A. pp. 172–179.
- **Review:** The case study "An international success amid uncertainty: Ozone and the Montreal Protocol. Appendix A, pp. 179-186.

b) **Watch**: Pamela Matson (Director). (2014, January 10). *Linking Knowledge to Actions in Mexico's Yacqui Valley* [Video recording]. https://www.youtube.com/watch?v=TqBmeP0udFU. **Watch minutes 12:25–45:35** (the Yaqui Valley story).

Study Questions to help you get the most out of the readings:

I. **Applying the SCL Framework to Yaqui Valley:** According to Matson et al., for knowledge to influence action it must be salient (relevant to users' decision needs), credible (meeting standards of scientific adequacy and technical competence), and legitimate (produced through processes that consider the values and perspectives of different actors). Analyze the Yaqui Valley case using this

framework. Why did the Stanford team's initial efforts (publication in elite science journal *Nature*, workshops) fail to change farmer behavior despite presenting win-win opportunities? What does this case reveal about how SCL actually works in practice?

II. **The Four Enterprises in Yaqui Valley:** Matson et al. argue that linking knowledge with action requires seeing the work as collaborative, systems-oriented, adaptive, and political. Trace how each of these dimensions appeared in the Yaqui Valley project. Which dimension did the team initially underestimate? What were the consequences of this underestimation, and how did their approach change once they recognized what they had missed?

III. **Boundary Work in Different Contexts:** Analyze the boundary work in both the Yaqui Valley and Ozone cases. In Yaqui Valley, what forms of boundary work did the Stanford team attempt, and why did their initial efforts fail? What did they learn about the actual knowledge system? In the ozone case, Benedict emphasizes that scientific assessments were "critical to the Montreal Protocol discussions." According to the case, what did these coordinated assessments accomplish that individual scientific papers did not?

IV. **Power and Knowledge in Action:** Both cases illustrate how power shapes whether knowledge influences action. In Yaqui Valley, analyze the different forms of power at play in determining whose knowledge farmers followed. In the ozone case, Benedict notes that US chemical companies eventually supported international regulation while European companies resisted. According to the case, what factors explain these different positions, and how did this affect the negotiations? What role did the Montreal Protocol's design features play in managing these dynamics?

V. **Your Case:** Think about a sustainability challenge you're familiar with where scientific knowledge could in principle inform action. In what ways and to what extent was that potential realized? What actors control the channels through which knowledge reaches decision-makers? How do existing power relationships shape what knowledge is considered legitimate or actionable? What forms of boundary work might help bridge the knowledge-action gap in this case?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

c) **Watch**: The full Matson lecture from reading ‘b’ (especially minutes 0:00–12:20) which provides valuable context on how to be both a scholar and an agitator in sustainability science.

d) **Read:** Clark, W. C., Tomich, T. P., Noordwijk, M. van, Guston, D., Catacutan, D., Dickson, N. M., & McNie, E. (2016). Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). *Proceedings of the National Academy of Sciences*, *113*(17), 4615–4622. https://doi.org/10.1073/pnas.0900231108
This paper presents a sophisticated framework for understanding how different contexts (sources and uses of knowledge) require different strategies for linking knowledge with action.

e) **Read**: Wyborn, C., Datta, A., Montana, J., Ryan, M., Leith, P., Chaffin, B., Miller, C., & van Kerkhoff, L. (2019). Co-producing sustainability: Reordering the governance of science, policy, and practice. *Annual Review of Environment and Resources*, *44*(1), 319–346. https://doi.org/10.1146/annurev-environ-101718-033103
A comprehensive review of co-production scholarship that critically examines both opportunities and challenges.

f) **Read:** Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J., & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences*, *100*(14), 8086–8091. https://doi.org/10.1073/pnas.1231332100
The foundational paper on salience, credibility, and legitimacy in knowledge systems.

Unit 3.7 Capacity to transform unstainable development pathways: How can we move beyond isolated actions to move whole sectors or regions to more sustainable development pathways?

Transformative capacity represents the culmination of our exploration of capacities for sustainable development. Of all the capacities, transformation uniquely requires orchestrating multiple other capacities toward a fundamental restructuring of development pathways—from unsustainable to sustainable ones. Transformations are shifts from one regime and its associated development pathways to another. Unlike adaptation (Unit 3.4) which seeks to maintain systems within their current regimes, often through dampening feedbacks, transformation involves fundamentally restructuring systems often through reinforcing or amplifying feedbacks that push toward new states. Sustainability transformations are shifts from regimes associated with unsustainable pathways to alternative regimes where development pathways are provisionally more sustainable—such as shifts from fossil fuel-based to renewable energy systems, or from industrial agriculture to agroecological food systems.

The need for transformations arises when current regimes prove fundamentally unsustainable. Path dependence and lock-in can make incremental adaptation insufficient or even counterproductive for long-term sustainability. Research over the past two decades has revealed that development pathways are stabilized by assemblages of institutions (rules, norms, beliefs), technologies, and incumbent power structures that resist change. Dominant pathways exhibit lock-in through increasing returns to scale and powerful interests threatened by decline. Yet transformations do occur—driven by novelty and innovation at micro-levels, exploiting windows of opportunity at macro-levels, and navigating tensions between speed of change and equity concerns.

The heart of transformative capacity is innovation—but not innovation for market returns alone. It requires actors across society to orient their innovative efforts toward collective goals that transcend individual gain, fostering change not just in technologies but in institutions, social practices, and the very goals that guide development. This unit explores what science and practice reveal about fostering such deliberate transformations—from understanding the multi-level dynamics that enable change, to creating shared visions that make transformation conceivable, to organizing mission-driven efforts that reshape markets toward sustainability.

Preparation for class: To prepare for this Unit, please:

a) **Read**: Harley, A. G., & Clark, W. C. (2025). *Building Capacity to Transform Unsustainable Development Pathways into Sustainable Ones: Lessons from scholarship and practice* (Nos. 25–03; Sustainability Science Program Working Paper, p. 21). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Transform%20Capacity_SSP%20Working%20Paper_Final.pdf (Available in Course Library)
This working paper synthesizes insights from transitions scholarship and contemporary practice, examining what's needed to shift from unsustainable to sustainable development pathways.

b) **Read**: Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science*, *357*(6357), 1242–1244. https://doi.org/10.1126/science.aao3760.
This concise paper broadens findings from the German Energiewende to general lessons for decarbonization, offering an authoritative summary of strategies to support goal-oriented transitions toward a lower carbon future. The authors emphasize "coevolutionary interactions between technologies and societal groups" rather than narrow technological approaches.

c) **Read**: Kattel, R., & Mazzucato, M. (2018). Mission-oriented innovation policy and dynamic capabilities in the public sector. *Industrial and Corporate Change*, *27*(5), 787–801. https://doi.org/10.1093/icc/dty032
This paper examines how governments can drive sustainability transformations through mission-oriented approaches that create new markets rather than simply fixing existing ones. The authors

argue that building transformative capacity requires public sector capabilities to coordinate across sectors, take risks, and maintain long-term vision in the face of uncertainty.

d) **Watch**: Klein, N., & Crabapple, M. (2019, April 17). A message from the future with Alexandria Ocasio-Cortez. *The Intercept*. https://theintercept.com/2019/04/17/green-new-deal-short-film-alexandria-ocasio-cortez/

This short film uses the power of storytelling to make radical climate transformation feel both urgent and possible. Narrated by Alexandria Ocasio-Cortez from the year 2030, it turns policy into human narrative, showing how society might rebuild itself around justice and sustainability.

e) **Review**: The Appalachia case from Unit 2.6, i.e. Harley, A., & Wexner, H. (2022). The Struggle for Sustainable Development in Appalachia's Mineral Rich Mountains. *Sustainability Science Program Working Paper*, *2022*(1), 65. and in the Course Library.

As you re-read, consider how the institutional arrangements and power structures you analyzed in Unit 2.6 create lock-in that prevents transformation away from extractive industries.

Study Questions to help you get the most out of the readings:

I. **Multi-level dynamics:** The Geels et al. paper (reading 'b') analyzes transformations through the Multi-Level Perspective: niche innovations (micro), regimes (meso), and landscape pressures (macro). Using the transformation imagined in "A Message from the Future" (reading 'd'), identify: What landscape pressures create openings for change? What regime elements are being challenged? What niche innovations are emerging? How must these three levels align for transformation to occur?

II. **Regimes and incumbent resistance**: Reading 'a' discusses how development pathways are stabilized by "assemblages of institutions, technologies, and power structures that resist change." Using the Appalachia case (reading 'e'), identify what keeps the region locked into extractive industries. How does power operate not just through active resistance but also by making alternatives seem unrealistic or unthinkable? How do "increasing returns to scale and powerful interests threatened by decline" explain coal's persistence despite its decline?

III. **Imaginaries and transformation**: "A Message from the Future" (reading 'd') presents an imaginary of transformed futures. How does this narrative approach differ from traditional policy proposals in building public support? What role do such imaginaries play in making radical system change conceivable when actors are locked into incremental responses?

IV. **Mission-oriented transformation**: Reading 'c' presents mission-oriented policy as essential for sustainability transformations. How does their "market-shaping" approach differ fundamentally from traditional "market-fixing" policy? Consider the transformation in "A Message from the Future" (reading 'd') - what specific market-shaping interventions would be needed to achieve it? How do these interventions go beyond simply correcting market failures to actively creating new markets and directing innovation toward collective goals?

V. **Your case**: Consider a specific transformation needed in your case—shifting from an unsustainable development pathway to a sustainable one. First, map how each of the six capacities from Part III would contribute to this transformation. Then analyze: Which capacities are currently strong or weak in your case? More importantly, what would it take to align these capacities toward a common mission as reading 'c' suggests? Is transformation failing because key capacities are missing, or because existing capacities aren't coordinated toward a shared purpose?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

f) **Read**: Jasanoff, S., & Kim, S.-H. (2009). Containing the Atom: Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea. *Minerva (London)*, *47*(2), 119–146. https://doi.org/10.1007/s11024-009-9124-4

This foundational article introduces the concept of "sociotechnical imaginaries"—collectively held visions of desirable futures. By comparing how the US and South Korea differently imagined nuclear power's role in their national development, the authors show how imaginaries influence which transformative pathways societies envision and pursue.Jasanoff, S. (2018). Just transitions: A humble approach to global energy futures. *Energy Research & Social Science*, *35*, 11–14. https://doi.org/10.1016/j.erss.2017.11.025

g) **Read**: Kern, F., & Howlett, M. (2009). Implementing transition management as policy reforms: A case study of the Dutch energy sector. *Policy Sciences*, *42*(4), 391–408. https://doi.org/10.1007/s11077-009-9099-x

This case study explores how the Netherlands attempted to govern energy system transformation through transition management approaches. The authors analyze the practical challenges of implementing transformation governance, including coordination across scales, managing competing interests, and balancing long-term vision with short-term political pressures.

Unit 4.1 Next Steps: How do leaders catalyze progress in the pursuit of sustainability?

Humans are capable of great change. In the course of our history "we, the peoples"* of the earth have moved, unevenly but persistently, towards a world with increased wellbeing for more and more of its inhabitants. We have eradicated diseases, abolished slavery as a legal institution, lengthened lifespans, and codified rights to protect poor and marginalized groups. Taking this progress for granted, however, or expecting it to simply continue, will almost certainly doom us. Moving collectively towards a better world for all takes hard work.

Sustainability is a critical way of looking at the world not just as it is, but as it could be if we do that work. The frameworks, concepts, and theories surrounding sustainability we have introduced in this course are meant to help you contribute to the work at hand: to think through the challenges of sustainable development, to design actions that could help address them, and to build the capacities needed for implementing such actions. But implementation doesn't just happen. It also requires leadership. We therefore turn in this last Unit of the course to the question "How do leaders catalyze progress in the pursuit of sustainability?"

Our answer to this final question, as might be predictable given what has come before in the course, is "it depends on context." Leading a community effort to better insulate low-income housing obviously requires different skills than leading an international effort to reduce plastic pollution. And the in-depth case studies we have used throughout the course illustrate the wide range of leadership approaches that have gained some success in the pursuit of sustainability at different places and times around the world. That said, some generalizations have begun to emerge. Matson et al., in the reading assigned for this Unit, draw on a wide range of experience to outline what they see to be mindsets shared by most successful sustainability leaders:

- They are empathetic problem-framers, focusing attention on the well-being of people not only in the here and now but also in distant places and future generations;
- They are systems thinkers, embracing the complexity of nature-society interactions and the need for mobilizing multi-disciplinary teams for understanding them;
- They are adaptive strategists, acknowledging the limits of our understanding and the consequent need to embrace surprise and failure;
- They are passionate but patient change-makers, recognizing the need for immediate but persistent advocacy to bring about transformational change at scale.

In the "Study Questions" for this Unit, we invite you to consider the applicability of these generalizations to a range of specific situations, and to reflect on other opportunities for leadership in the pursuit of sustainability.

Preparation for class: To prepare for this Unit, please:

a) **Read**: Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press. "Next Steps: Contributing to a Sustainability Transition," Ch. 6**,** pp.129-142.

Study Questions to help you get the most out of the readings:

I. **Generalizations vs. context-dependence**: The readings for this Unit sketch 2 very different instances of leaders taking sustainability-related ideas into practice: Maria Foronda as an environmental activist in Peru and Ray Anderson as a CEO of a global textile manufacturer. What

* This is the phrase that opens the Charter to the United Nations

were the common features of their individual leadership strategies? How and why did their approaches differ? To what extent do the generalizations regarding the "mindsets of sustainability leaders" that are summarized in this note and discussed in the readings help to make sense of the specific cases of Foronda and Anderson?

II. **Leadership at home**: Imagine that you have been asked to lead an effort to radically reduce carbon emissions in some specific context where you live or work (e.g. a place where you have lived, a school you have attended, an organization where you have worked, etc.). Outline the initial approach you would take to bring relevant actors together in defining shared goals, identifying and evaluating possible interventions, building the capacity for implementation, mobilizing action and securing long term commitments to sustain it over the long run. Which of the generalizations about effective leadership for sustainability discussed in the readings were helpful in designing your approach? Why? What key elements of your approach derive from the particular context of the effort you have been asked to lead? What aspects of your leadership approach would you feel comfortable recommending to someone facing a similar challenge? Why?

III. **Your case**: For the case study of sustainable development that you chose to pursue throughout this course, consider the same questions outlined in (II) above, i.e. How would you lead—or advise existing leaders—in efforts to advance pursuit of sustainability there? Why?

Digging deeper (optional materials for further exploring frontiers in the pursuit of sustainability):

b) **Read**: Johnson, A. E., & Wilkinson, K. K. (Eds.). (2020). *All we can save: Truth, courage, and solutions for the climate crisis*. One World.

This anthology showcases diverse forms of sustainability leadership through essays, poetry, and art by women leaders across multiple fields—from regenerative agriculture to climate finance to community organizing.

c) **Read**: Solnit, R. (2025). *No straight road takes you there: Essays for uneven terrain*. Haymarket Books.

Solnit examines how transformative change toward sustainability actually happens—often indirectly, unpredictably, and through accumulated efforts whose impacts only become visible later. Her insights about persistence through apparent failure apply directly to the long-term work of sustainability leadership.

Bibliography

Adaptation at Altitude: Solutions Portal. (n.d.). Adaptation At Altitude. Retrieved October 12, 2025, from https://adaptationataltitude.org/solutionsportal/

Anadon, L. D., Chan, G., Harley, A. G., Matus, K., Moon, S., Murthy, S. L., & Clark, W. C. (2016a). Making technological innovation work for sustainable development. *Proceedings of the National Academy of Sciences*, *113*(35), 9682–9690. https://doi.org/10.1073/pnas.1525004113

Anadon, L. D., Chan, G., Harley, A. G., Matus, K., Moon, S., Murthy, S. L., & Clark, W. C. (2016b). Making technological innovation work for sustainable development. *Proceedings of the National Academy of Sciences*, *113*(35), 9682–9690. https://doi.org/10.1073/pnas.1525004113

Arrow, K. J., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Levin, S. A., Mäler, K.-G., Schneider, S., Starrett, D., & Walker, B. H. (2004). Are We Consuming Too Much? *Journal of Economic Perspectives*, *18*(3), Article 3.

Barrett, C. B., Travis, A. J., & Dasgupta, P. (2011). On biodiversity conservation and poverty traps. *Proceedings of the National Academy of Sciences*, *108*(34), 13907–13912. https://doi.org/10.1073/pnas.1011521108

Bennett, H. (2017, November 2). Have psychologists found a better way to persuade people to save the planet? *The Guardian*. https://www.theguardian.com/inequality/2017/nov/02/psychologists-better-way-persuade-people-to-save-planet-environment

Biggs, R., Peterson, G. D., & Rocha, J. C. (2018). The Regime Shifts Database: A framework for analyzing regime shifts in social-ecological systems. *Ecology and Society*, *23*(3), 9–9. https://doi.org/10.5751/ES-10264-230309

Boston, J. (2017). *Governing for the Future: Designing Democratic Institutions for a Better Tomorrow* (First edition). Emerald.

Capitals Approach. (n.d.). *Capitals Coalition*. Retrieved October 12, 2025, from https://capitalscoalition.org/capitals-approach/

Caradonna, J. L. (2014). *Sustainability: A History*. Oxford University Press.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J., & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences*, *100*(14), 8086–8091. https://doi.org/10.1073/pnas.1231332100

Chancel, L. (2020). *Unsustainable inequalities: Social justice and the environment*. The Belknap Press of Harvard University Press.

Chaplin-Kramer, R., Neugarten, R. A., Sharp, R. P., Collins, P. M., Polasky, S., Hole, D., Schuster, R., Strimas-Mackey, M., Mulligan, M., Brandon, C., Diaz, S., Fluet-Chouinard, E., Gorenflo, L. J., Johnson, J. A., Kennedy, C. M., Keys, P. W., Longley-Wood, K., McIntyre, P. B., Noon, M., … Watson, R. A. (2023). Mapping the planet's critical natural assets. *Nature Ecology & Evolution*, *7*(1), 51–61. https://doi.org/10.1038/s41559-022-01934-5

Chenoweth, E. (2021). *Civil resistance: What everyone needs to know*. Oxford University Press.

Clark, W. C., & Harley, A. G. (2020a). Framework for Research in Sustainability Science (video presentation 15 mins). In National Academies of Sciences, Engineering and Medicine (Ed.), *Progress Challenges and Opportunities for Sustainability Science A Workshop* (p. 15 mins.). National Academies of Science (USA). https://scholar.harvard.edu/files/wclark/files/framework_for_research_in_sustainability_science_nas.mp4

Clark, W. C., & Harley, A. G. (2020b). Sustainability Science: Toward a Synthesis. *Annual Review of Environment and Resources*, *45*, 331–386. https://doi.org/10.1146/annurev-environ-012420-043621

Clark, W. C., & Harley, A. G. (2020c). Sustainability Science: Toward a Synthesis. *Annual Review of Environment and Resources*, *45*(1), 331–386. https://doi.org/10.1146/annurev-environ-012420-043621

Clark, W. C., & Harley, A. G. (2025a). *NetLogo Guide for Sustainable Development Course* (Course Library for Sustainable Development Course). Harvard University.

Clark, W. C., & Harley, A. G. (2025b). *Non-linear behavior in paper folding* (Course Library for Sustainable Development Course). Harvard University.

Clark, W. C., Tomich, T. P., Noordwijk, M. van, Guston, D., Catacutan, D., Dickson, N. M., & McNie, E. (2016). Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). *Proceedings of the National Academy of Sciences*, *113*(17), 4615–4622. https://doi.org/10.1073/pnas.0900231108

Conway, G., & Waage, J. (2010). *Science and Innovation for Development*. UK Collaborative on Development Sciences (UKCDS).

Dasgupta, P. (2004). *Human Well-Being and the Natural Environment* (1st paperback, with revised Appendix). Oxford University Press.

Dasgupta, P. (2014). Measuring the wealth of nations. *Annual Review of Resource Economics*, *6*(1), 17–31. https://doi.org/10.1146/annurev-resource-100913-012358

Dasgupta, P. (2021a). *The economics of biodiversity: The Dasgupta Review*. https://royalsociety.org/news-resources/projects/biodiversity/economics-biodiversity/

Dasgupta, P. (2021b). *The economics of biodiversity (The Dasgupta Review)*. HM Treasury. https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review

Dasgupta, P., Managi, S., & Kumar, P. (2021). The inclusive wealth index and sustainable development goals. *Sustainability Science*. https://doi.org/10.1007/s11625-021-00915-0

Deaton, A. (2013). *The Great Escape: Health, Wealth, and the Origins of Inequality*. Princeton University Press.

Dryzek, J. S. (2016). Institutions for the Anthropocene: Governance in a changing Earth system. *British Journal of Political Science*, *46*(4), 937–956. https://doi.org/10.1017/S0007123414000453

Edelman. (2024). *Why we study Trust*. Edelman. https://www.edelman.com/trust

Eriksen, S., Schipper, E. L. F., Scoville-Simonds, M., Vincent, K., Adam, H. N., Brooks, N., Harding, B., Khatri, D., Lenaerts, L., Liverman, D., Mills-Novoa, M., Mosberg, M., Movik, S., Muok, B., Nightingale, A., Ojha, H., Sygna, L., Taylor, M., Vogel, C., & West, J. J. (2021). Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Development*, *141*, 105383. https://doi.org/10.1016/j.worlddev.2020.105383

Gaventa, J. (1980). *Power and Powerlessness: Quiescence and Rebellion in an Appalachian Valley*. University of Illinois Press.

Geels, F. W. (2006). The hygienic transition from cesspools to sewer systems (1840–1930): The dynamics of regime transformation. *Research Policy*, *35*, 1069–1082. https://doi.org/10.1016/j.respol.2006.06.001

Geels, F. W., Kern, F., & Clark, W. C. (2023). System transitions research and sustainable development: Challenges, progress, and prospects. *Proceedings of the National Academy of Sciences*, *120*(47), e2206230120. https://doi.org/10.1073/pnas.2206230120

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science*, *357*(6357), 1242–1244. https://doi.org/10.1126/science.aao3760

Global Witness. (2023). *Standing firm: The Land and Environmental Defenders on the frontlines of the climate crisis*. https://globalwitness.org/en/campaigns/land-and-environmental-defenders/standing-firm/

Goldstein, J. H., Caldarone, G., Duarte, T. K., Ennaanay, D., Hannahs, N., Mendoza, G., Polasky, S., Wolny, S., & Daily, G. C. (2012). Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(19), 7565–7570. https://doi.org/10.1073/pnas.1201040109

Hamilton, K. E., Helliwell, J. F., & Woolcock, M. (2016). *Social capital, trust, and well-being in the evaluation of wealth* (No. WPS7707; pp. 1–23). The World Bank. http://documents.worldbank.org/curated/en/249031468195550873/Social-capital-trust-and-well-being-in-the-evaluation-of-wealth

Hardin, G. (1968). The tragedy of the commons. *Science*, *162*, 1243–1248.

Harley, A. G. (2021a). *Looking outward: Refocusing attention on London's hinterland (Addendum to London: A multi-century struggle for sustainable development in an urban environment)* (Course Library for Sustainable Development Course). Harvard University.

Harley, A. G. (2021b). *Uganda Reading Guide for a course in sustainable development* (Course Library for Sustainable Development Course, p. 17). Harvard University.

Harley, A. G. (2025). *A framework for thinking about actors, institutions and power in nature-society systems* (Course Library for Sustainable Development Course). Harvard University.

Harley, A. G., & Clark, W. C. (2025a). *Building Capacity to Adapt Development Pathways to Protect Human Well-being in the Face of Shocks: Lessons from scholarship and practice* (Nos. 25–02; Sustainability Science Program Working Paper, p. 20). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Adaptation%20Capacity_SSP%20Working%20Paper_FINAL.pdf

Harley, A. G., & Clark, W. C. (2025b). *Building Capacity to Govern Cooperatively in Pursuit of Sustainable Development: Lessons from scholarship and practice* (Nos. 25–06; Sustainability Science Program Working Paper, p. 20). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Governance%20Capacity_SSP%20Working%20Paper_Final.pdf

Harley, A. G., & Clark, W. C. (2025c). *Building Capacity to Measure Sustainability: Lessons from scholarship and practice* (Nos. 25–01; Sustainability Science Program Working Paper, p. 18). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Measurement%20Capacity_SSP%20Working%20Paper.pdf

Harley, A. G., & Clark, W. C. (2025d). *Building Capacity to Promote Equity with and among Generations: Lessons from scholarship and practice* (Nos. 25–04; Sustainability Science Program Working Paper, pp. 1–19). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Equity%20Capacity_SSP%20Working%20Paper.pdf

Harley, A. G., & Clark, W. C. (2025e). *Building Capacity to Transform Unsustainable Development Pathways into Sustainable Ones: Lessons from scholarship and practice* (Nos. 25–03; Sustainability Science Program Working Paper, p. 21). Harvard Kennedy School of Government. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/programs/sustsci/files/Transform%20Capacity_SSP%20Working%20Paper_Final.pdf

Harley, A., & Wexner, H. (2022). *The Struggle for Sustainable Development in Appalachia's Mineral Rich Mountains* (Course Library for Sustainable Development Course, p. 65). Mossavar-Rahmani Center for Business and Government. https://dash.harvard.edu/handle/1/37371772

Harley, Alicia G. (Director). (2025, February 12). *Capacity building to measure progress toward sustainable development* [Video recording]. M-RCBG_Harvard. https://www.youtube.com/watch?v=1cYCqBiBwgg

Hasell, J., Rohenkohl, B., Arriagada, P., Ortiz-Ospina, E., & Roser, M. (2023). Economic Inequality. *Our World in Data*. https://ourworldindata.org/economic-inequality

Hess, C., & Ostrom, E. (2007). Introduction: An overview of the knowledge commons. In C. Hess & E. Ostrom (Eds.), *Understanding Knowledge as a Commons: From Theory to Practice* (pp. 3–26). MIT Press.

Hilborn, R., & Costello, C. (2018). The potential for blue growth in marine fish yield, profit and abundance of fish in the ocean. *Marine Policy*, *87*, 350–355. https://doi.org/10.1016/j.marpol.2017.02.003

Hoen, E. 't, Berger, J., Calmy, A., & Moon, S. (2011). Driving a decade of change: HIV/AIDS, patents and access to medicines for all. *Journal of the International AIDS Society*, *14*, 15. https://doi.org/10.1186/1758-2652-14-15

Hull, V., & Liu, J. (2018). Telecoupling: A new frontier for global sustainability. *Ecology and Society*, *23*(4), art11. https://doi.org/10.5751/ES-10494-230441

Iler, S., & Clark, W. (2025). *NetLogo: Exploring Stocks and Flows for Climate Change*. Harvard University.

Jasanoff, S. (2018). Just transitions: A humble approach to global energy futures. *Energy Research & Social Science*, *35*, 11–14. https://doi.org/10.1016/j.erss.2017.11.025

Jasanoff, S., & Kim, S.-H. (2009). Containing the Atom: Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea. *Minerva (London)*, *47*(2), 119–146. https://doi.org/10.1007/s11024-009-9124-4

Johnson, A. E., & Wilkinson, K. K. (Eds.). (2020). *All we can save: Truth, courage, and solutions for the climate crisis*. One World.

Jumbri, I. A., Ikeda, S., & Managi, S. (2018). Heterogeneous global health stock and growth: Quantitative evidence from 140 countries, 1990–2100. *Archives of Public Health*, *76*(1), 81. https://doi.org/10.1186/s13690-018-0327-8

Kamau, M. (with Chasek, P. S., & O'Connor, D. C.). (2018). *Transforming multilateral diplomacy: The inside story of the Sustainable Development Goals*. Routledge, Taylor & Francis Group.

Kashwan, P. (2017). Inequality, democracy, and the environment: A cross-national analysis. *Ecological Economics*, *131*, 139–151. https://doi.org/10.1016/j.ecolecon.2016.08.018

Kattel, R., & Mazzucato, M. (2018). Mission-oriented innovation policy and dynamic capabilities in the public sector. *Industrial and Corporate Change*, *27*(5), 787–801. https://doi.org/10.1093/icc/dty032

Kern, F., & Howlett, M. (2009). Implementing transition management as policy reforms: A case study of the Dutch energy sector. *Policy Sciences*, *42*(4), 391–408. https://doi.org/10.1007/s11077-009-9099-x

Klein, N., & Crabapple, M. (2019, April 17). A message from the future with Alexandria Ocasio-Cortez. *The Intercept*. https://theintercept.com/2019/04/17/green-new-deal-short-film-alexandria-ocasio-cortez/

Kousky, C. (2019). The role of natural disaster insurance in recovery and risk reduction. *Annual Review of Resource Economics*, *11*(1), 399–418. https://doi.org/10.1146/annurev-resource-100518-094028

Krausmann, F., Schandl, H., Eisenmenger, N., Giljum, S., & Jackson, T. (2017). Material flow accounting: Measuring global material use for sustainable development. *Annual Review of Environment and Resources*, *42*(1), 647–675. https://doi.org/10.1146/annurev-environ-102016-060726

Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H., & Haberl, H. (2017). Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proceedings of the National Academy of Sciences*, *114*(8), 1880–1885. https://doi.org/10.1073/pnas.1613773114

Kurzgesagt – In a Nutshell (Producer). (2016). *Overpopulation – The Human Explosion Explained* [Video recording]. https://www.youtube.com/watch?v=QsBT5EQt348

Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., & Arrow, K. (2013). Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics*, *18*(2), 111–132.

Lintsen, H., Veraart, F., Smits, J.-P., & Grin, J. (2018). *Well-being, Sustainability and Social Development: The Netherlands 1850-2050*. Springer International Publishing. https://doi.org/10.1007/978-3-319-76696-6

Liu, J. (2023). Leveraging the metacoupling framework for sustainability science and global sustainable development. *National Science Review*, *10*(7), nwad090. https://doi.org/10.1093/nsr/nwad090

Lundborg, P., Nordin, M., & Rooth, D. O. (2018). The intergenerational transmission of human capital: The role of skills and health. *Journal of Population Economics*, *31*(4), Article 4. https://doi.org/10.1007/s00148-018-0702-3

Matson, P. A., Clark, W. C., & Andersson, K. P. (2016). *Pursuing sustainability: A guide to the science and practice*. Princeton University Press. https://pursuing-sustainability.stanford.edu/

Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing Sustainability: A Guide to the Science and Practice*. Princeton University Press.

Mazzucato, M., & Kattel, R. (2020). COVID-19 and public-sector capacity. *Oxford Review of Economic Policy*, *36*(Supplement_1), S256–S269. https://doi.org/10.1093/oxrep/graa031

McNeill, J. R. (with Engelke, P.). (2016). *The Great Acceleration: An Environmental History of the Anthropocene Since 1945*. Belknap Press of Harvard University Press.

Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.

Meadows, D., Sterman, J., & King, A. (2024). *Fishbanks: A Renewable Resource Management Simulation*. https://mitsloan.mit.edu/teaching-resources-library/fishbanks-a-renewable-resource-management-simulation

Meyfroidt, P., Roy Chowdhury, R., de Bremond, A., Ellis, E. C., Erb, K.-H., Filatova, T., Garrett, R. D., Grove, J. M., Heinimann, A., Kuemmerle, T., Kull, C. A., Lambin, E. F., Landon, Y., le Polain de Waroux, Y., Messerli, P., Müller, D., Nielsen, J. Ø., Peterson, G. D., Rodriguez García, V., … Verburg, P. H. (2018). Middle-range theories of land system change. *Global Environmental Change*, *53*, 52–67. https://doi.org/10.1016/j.gloenvcha.2018.08.006

Milanovic, B. (2024). The three eras of global inequality, 1820–2020 with the focus on the past thirty years. *World Development*, *177*, 106516. https://doi.org/10.1016/j.worlddev.2023.106516

Milfont, T. L., Bain, P. G., Kashima, Y., Corral-Verdugo, V., Pasquali, C., Johansson, L.-O., Guan, Y., Gouveia, V. V., Garðarsdóttir, R. B., Doron, G., Bilewicz, M., Utsugi, A., Aragones, J. I., Steg, L.,

Soland, M., Park, J., Otto, S., Demarque, C., Wagner, C., … Einarsdóttir, G. (2018). On the relation between social dominance orientation and environmentalism: A 25-nation study. *Social Psychological and Personality Science*, *9*(7), 802–814. https://doi.org/10.1177/1948550617722832

Muller, N. Z., Mendelsohn, R., & Nordhaus, W. D. (2011). Environmental accounting for pollution in the United States economy. *American Economic Review*, *101*(5), 1649–1675.

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources*, *32*(1), 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348

OECD. (n.d.-a). *OECD Better Life Index*. Retrieved July 1, 2024, from https://www.oecdbetterlifeindex.org/

OECD. (2020). *How's Life? 2020: Measuring Well-being*. OECD. https://doi.org/10.1787/9870c393-en

OECD. (n.d.b). *Well-being and beyond GDP*. OECD. https://www.oecd.org/en/topics/well-being-and-beyond-gdp.html

Ortiz-Ospina, E., Roser, M., & Arriagada, P. (2024). Trust. *Our World in Data*. https://ourworldindata.org/trust

Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B., & Policansky, D. (1999). Revisiting the Commons: Local Lessons, Global Challenges. *Science*, *284*(5412), 278–282. https://doi.org/10.1126/science.284.5412.278

Our Children's Trust. (n.d.). *Juliana v. United States*. Retrieved October 12, 2025, from https://www.ourchildrenstrust.org/juliana-v-us

Pamela Matson (Director). (2014, January 10). *Linking Knowledge to Actions in Mexico's Yacqui Valley* [Video recording]. https://www.youtube.com/watch?v=TqBmeP0udFU

Roberts, C., Béné, C., Bennett, N., Boon, J. S., Cheung, W. W. L., Cury, P., Defeo, O., De Jong Cleyndert, G., Froese, R., Gascuel, D., Golden, C. D., Hawkins, J., Hobday, A. J., Jacquet, J., Kemp, P., Lam, M. E., Le Manach, F., Meeuwig, J. J., Micheli, F., … O'Leary, B. C. (2024). Rethinking sustainability of marine fisheries for a fast-changing planet. *Npj Ocean Sustainability*, *3*(1), 41. https://doi.org/10.1038/s44183-024-00078-2

Roser, M. (2024). *Our world in data*. https://ourworldindata.org/

Sabin Center for Climate Change Law, Columbia Univ. (n.d.). *The Climate Litigation Database*. Retrieved October 12, 2025, from https://www.climatecasechart.com

Scheffer, M., van Bavel, B., van de Leemput, I. A., & van Nes, E. H. (2017). Inequality in nature and society. *Proceedings of the National Academy of Sciences*, *114*(50), 13154–13157. https://doi.org/10.1073/pnas.1706412114

Schipper, L., & Mukherji, A. (2024). Misguided negative adaptation narratives are hurting the poor. *Science*, *386*(6722), 624–626. https://doi.org/10.1126/science.adq7821

Schlager, E., & Ostrom, E. (1992). Property-Rights Regimes and Natural Resources: A Conceptual Analysis. *Land Economics*, *68*(3), Article 3. https://doi.org/10.2307/3146375

Schlüter, M., Caniglia, G., Orach, K., Bodin, Ö., Magliocca, N., Meyfroidt, P., & Reyers, B. (2022). Why care about theories? Innovative ways of theorizing in sustainability science. *Current Opinion in Environmental Sustainability*, *54*, 101154. https://doi.org/10.1016/j.cosust.2022.101154

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

Sen, A. (2000). *Development as Freedom* (1st Anchor Books ed.). Anchor Books.

Södersten, C.-J., Wood, R., & Wiedmann, T. (2020). The capital load of global material footprints. *Resources, Conservation and Recycling*, *158*, 104811. https://doi.org/10.1016/j.resconrec.2020.104811

Solnit, R. (2025). *No straight road takes you there: Essays for uneven terrain*. Haymarket Books.

Solow, R. (1993). An almost practical step toward sustainability. *Resources Policy*, *19*(3), 162–172. https://doi.org/10.1016/0301-4207(93)90001-4

State and Trends in Adaptation: Report 2022. (2022). Global Center on Adaptation. https://gca.org/reports/sta22/

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. https://doi.org/10.1073/pnas.1810141115

Steiner, A. (Director). (2020, December). *Humanity's planet-shaping powers—And what they mean for the future | TED Talk* [Video recording]. https://www.ted.com/talks/achim_steiner_humanity_s_planet_shaping_powers_and_what_they_mean_for_the_future

Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.

Sterman, J. (2002). *System Dynamics: Systems Thinking and Modeling for a Complex World* [Working Paper]. Massachusetts Institute of Technology. Engineering Systems Division. https://dspace.mit.edu/handle/1721.1/102741

Sterman, J. (Director). (2011). *Fishbanks: A renewable resource management simulation: A video introduction* [Video recording]. MIT Management Sloan School. https://forio.com/simulate/mit/fishbanks/simulation/login.html

Sterman, J. D. (2002). All models are wrong: Reflections on becoming a systems scientist. *System Dynamics Review*, *18*(4), 501–531. https://doi.org/10.1002/sdr.261

Sterman, J., & King, A. (2011). *Introduction to Fishbanks* (Nos. 11–133; p. 2). MIT Sloan Management. https://forio.com/simulate/mit/fishbanks/simulation/downloads/english/Fishbanks%20Introduction.pdf

Stiglitz, J. E., Fitoussi, J.-P., & Durand, M. (2018). *Beyond GDP: Measuring What Counts for Economic and Social Performance*. OECD. https://doi.org/10.1787/9789264307292-en

Supran, G., Rahmstorf, S., & Oreskes, N. (2023). Assessing ExxonMobil's global warming projections. *Science*, *379*(6628). https://doi.org/10.1126/science.abk0063

Sweeney, L. B. (Director). (n.d.). *In a world of systems* [YouTube]. Donella Meadows Institute. https://youtu.be/A_BtS008J0k

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249–286. https://doi.org/10.1002/sdr.198

Taylor, C. (2024). *Cosmic Connections: Poetry in the Age of Disenchantment* (1st ed.). Harvard University Press.

Thompson, M. (2021). *The Alaskan Salmon Fishery: Managing Resources in a Globalizing World* (Course Library for Sustainable Development Course). Harvard University.

United Nations. (2021). *THE 17 GOALS | Sustainable Development*. https://sdgs.un.org/goals

United Nations Department of Economic and Social Affairs. (n.d.). *Capacity Development*. Retrieved December 20, 2024, from https://sdgs.un.org/topics/capacity-development

United Nations Environment Programme. (2024). *Global Resources Outlook 2024: Bend the Trend – Pathways to a liveable planet as resource use spikes*. International Resource Panel. https://www.resourcepanel.org/reports/global-resources-outlook-2024

van Zanden, J. (2014). *How Was Life?: Global Well-being since 1820* (p. 273). OECD. https://www.oecd.org/statistics/how-was-life-9789264214262-en.htm

Wagner, G., Anthoff, D., Cropper, M., Dietz, S., Gillingham, K. T., Groom, B., Kelleher, J. P., Moore, F. C., & Stock, J. H. (2021). Eight priorities for calculating the social cost of carbon. *Nature*, *590*(7847), Article 7847. https://doi.org/10.1038/d41586-021-00441-0

Weisz, H., Suh, S., & Graedel, T. E. (2015). Industrial ecology: The role of manufactured capital in sustainability. *Proceedings of the National Academy of Sciences*, *112*(20), 6260–6264. https://doi.org/10.1073/pnas.1506532112

Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modeling: Modeling natural, social, and engineered complex systems with NetLogo*. The MIT press. https://www.intro-to-abm.com/

World Bank. (2024). *The Changing Wealth of Nations 2024: Revisiting the Measurement of comprehensive wealth* (No. 193950). World Bank Group. http://documents.worldbank.org/curated/en/099100824155021548

World Commission on Environment and Development. (1987). *Our Common Future*. United Nations. http://www.un-documents.net/wced-ocf.htm

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., Fogarty, M. J., Fulton, E. A., Hutchings, J. A., Jennings, S., Jensen, O. P., Lotze, H. K., Mace, P. M., McClanahan, T. R., Palumbi, S. R., Parma, A. M., Rikard, D., Rosenberg, A. A., Zeller, D., & Minto, C. (2009).

Rebuilding Global Fisheries. *Science*, *325*(5940), 578–585. https://doi.org/10.1016/j.marpol.2017.02.003

Wyborn, C., Datta, A., Montana, J., Ryan, M., Leith, P., Chaffin, B., Miller, C., & van Kerkhoff, L. (2019). Co-producing sustainability: Reordering the governance of science, policy, and practice. *Annual Review of Environment and Resources*, *44*(1), 319–346. https://doi.org/10.1146/annurev-environ-101718-033103

Zucman, G. (2019). Global wealth inequality. *Annual Review of Economics*, *11*(1), 109–138. https://doi.org/10.1146/annurev-economics-080218-025852