6 Social Science Perspectives on Carbon

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KEY FINDINGS

1. *Broadened Approaches*—A range of social scientific research approaches, including people-centered analyses of energy use, governance, vulnerability, scenarios, social-ecological systems, sociotechnical transitions, social networks, and social practices, complements physical science research and informs decision making. Approaches that are people centered and multidisciplinary emphasize that carbon-relevant decisions are often not about energy, transportation, infrastructure, or agriculture, as such, but rather about style, daily living, comfort, convenience, health, and other priorities (*very high confidence*).

2. *Assumed versus Actual Choices*—Planners have assumed economically rational energy-use and consumption behaviors and thus have failed to predict actual choices, behaviors, and intervening developments, leading to large gaps between predicted rates of economically attractive purchases of technologies with lower carbon footprints and actual realized purchase rates (*high confidence*).

3. *Social Nature of Energy Use*—Opportunities to go beyond a narrow focus on the energy-efficiency industry to recognize and account for the social nature of energy use include 1) engaging in market transformation activities aimed at upstream actors and organizations in supply chains, 2) implementing efficiency codes and standards for buildings and technologies, 3) conducting research to understand how people's behaviors socially vary and place different loads on even the most efficient energy-using equipment, and 4) adding consideration of what people actually do with energy-using equipment to plans for technology and efficiency improvements (*high confidence*).

4. *Governance Systems*—Research that examines governance at multiple formal levels (international, national, state/province, cities, other communities) as well as informal processes will identify overlaps and gaps and deepen understanding of effective processes and opportunities involved in carbon management, including a focus on benefits such as health, traffic management, agricultural sustainability, and reduced inequality (*medium confidence*).

6.1 Introduction: The Social Embeddedness of Carbon

The goal of this chapter is to provide perspectives of social science research and analysis that go beyond much of available carbon science work that is sector based and economically minded—research that as yet is not sufficiently reflected in carbon cycle studies. The research discussed in this chapter thus is not intended to be a comprehensive, integrated picture of the society-carbon interaction that produces carbon emissions. Rather, the framing of the research discussed here begins with people and their social structures. This framing is different from, but complementary to, that used in the research discussed in most other chapters in the *Second State of the Carbon Cycle Report* (SOCCR2; see Box 6.1, Two Framings of Research Relevant to the Carbon Cycle, p. 266).

The framing in most of SOCCR2 begins with a description of the carbon cycle in spatial and quantitative terms, proceeds to calculations of carbon emissions to the atmosphere and their sectoral sources, and then analyzes human activities that contribute to the carbon emissions in those sectors and the impacts that increasing emissions have on physical and social systems. This framing has been used in physical science research and extended to much energy and economics research, areas not covered in this chapter.

Knowledge gained through this research framing can identify opportunities for carbon management that target the largest emissions categories (e.g., fossil fuel–based energy and transportation, urban settings, and agriculture; see Ch. 3: Energy Systems, p. 110; Ch. 4: Understanding Urban Carbon Fluxes, p. 189; and Ch. 5: Agriculture, p. 229). However,

Box 6.1 Two Framings of Research Relevant to the Carbon Cycle

Framing starting with the carbon cycle (CC):
Global CC / Fluxes → Regional CC / Fluxes → Emissions by Sector → Social "Drivers"
Framing starting with people (this chapter):
Social Structures / Processes (SS/P) → Carbon Content of SS/P → Feasible Changes

barriers to such technically oriented opportunities exist in ways of life and social or governance structures at local to global levels.

This chapter, in contrast, discusses research conducted using a framing that begins with an analysis of social conditions and structures in which carbon plays various roles. In this alternative framing, 1) the myriad and interrelated ways carbon-embedded structures and processes support ways of life become evident and 2) the socially feasible pathways to opportunities for carbon management emerge in the larger societal context. Pathways indicated under research using a people-centered framing are likely to solve multiple social goals rather than trying to achieve the single goal of emissions reductions because institutions and groups (e.g., governments, businesses, and families) have a different and broader set of issues to deal with than carbon management. Similarly, decisions that affect carbon emissions will be based on multiple factors—often including economic costs but also family, time, job, convenience, what others do, what is best for the group or organization, and other considerations.

6.1.1 Carbon Embeddedness in Social Structures and Processes

Although carbon is part of (i.e., embedded in; see Box 6.2, Embedded Carbon, this page) most social structures and processes, it is largely invisible to people as they go about their daily lives. People may (or may not) think of carbon as they see smokestacks or burn wood in a campfire because the carbon-emitting processes that produce electricity, heat buildings, and drive industrial processes may stay in the background, out of sight and out of mind.

Box 6.2 Embedded Carbon

Social science perspectives describe social arrangements and practices and then identify how carbon is embedded in them. "Embeddedness" means that carbon is an integral but often invisible part of how people lead their lives, so they do not think of themselves as using carbon but instead see the services and products without seeing their embedded carbon. Moreover, people do not often make choices about carbon as such—they choose from what is available in the market.

Nevertheless, emissions and associated structures and processes start with people—their needs and wants and how various social, political, and economic configurations and technologies both shape and are shaped by those needs and wants. From energy choices and services to economic policies and from urban hardscapes to rural landscapes, carbon is emitted, conserved, or captured as people work, travel, eat, and engage in other everyday activities and as human institutions and economic systems form and operate (see Figure 6.1, p. 267).

Research that begins by examining social structures and practices analyzes categories that may include standard sectors such as energy, transportation, buildings, and agriculture, but starting with people brings in a wide range of other topics as well. Eating, for example, a seemingly straightforward activity, encompasses a vast system of farm and

Figure 6.1. Carbon Embeddedness. As people work, learn, run errands, travel, and enjoy family and civic life, carbon is a common "thread," running through their infrastructure, tools, and environment (represented here by the white "threads" in the figure). Thus, analysis of the carbon cycle will be enhanced by identifying human uses of and reliance on carbon.

food production, agricultural policies and supports, imports and exports, transportation, middleman transactions, retail stores (e.g., location and products offered), and people's preferences along with income and health considerations. Obtaining and keeping a job, considered in a people-centered systems approach, similarly involves a range of activities such as educational opportunities and costs; income levels; locational factors such as housing, transportation, and commercial buildings (and/or home offices); access to electronic technologies; and health insurance and other benefits—the list could go on.

Social science research that examines people and the social embeddedness of carbon includes different approaches based on the research questions to be answered but often emphasizes systems and network perspectives and multiple societal factors within those systems. Because these approaches represent lines of research not assessed in the *First State of the Carbon Cycle Report* (SOCCR1; CCSP 2007), some references may predate that document.

6.1.2 Chapter Structure

First, this chapter discusses five approaches that represent lines of social science research within the climate change community, lines that are well established but usually not framed as questions about societal relationships with carbon or the carbon cycle.

- Section 6.2, p. 268. At individual, institutional, and organizational levels, behavioral research explores connections among motivation,

intention, and actors with regard to energy-related consumption and other individual and social behaviors.

- Section 6.3, p. 274. Governance research provides insights into why and how policy-environment decisions are made and implemented through both informal and formal processes.
- Section 6.4, p. 276. Scenarios of the future point to the power of connecting climate change and carbon emissions to their social-economic (socioeconomic) consequences.
- Section 6.5, p. 278. Vulnerability assessments specify who will probably be harmed by climate change, what the harm will be, and where interventions can be made at regional and local levels.
- Section 6.6, p. 279. A socioecological systems perspective demonstrates linkages among climate change–related hazards and social vulnerabilities and risks.

Next, the chapter introduces three less well known social-scientific approaches that hold potential for increasing basic understanding and providing useful future directions for decision makers to consider.

- Section 6.7, p. 280. Sociotechnical transition studies illuminate how technological transitions happen as actors, artifacts, and processes shape and reshape each other.
- Section 6.8, p. 282. Social network analyses map the connections among people with similar interests and goals, thus showing potentially changeable pathways and roadblocks.
- Section 6.9, p. 282. Social practice analyses reveal the configurations that produce emissions but also support valued, or locked-in, ways of life.

The final three sections are crosscutting. Section 6.10, p. 284, points out the crucial roles that communication and stakeholder involvement play in people-centered research. Section 6.11, pp. 285, discusses opportunities to reduce carbon emissions, including individual and social actions at various levels and timescales. Finally, Section 6.12, p. 287, provides a brief summary of findings, as well as specific steps in the path for research related to social systems and embedded carbon.

Essential to research in all these areas is increased interaction between researchers and stakeholders. Economic theory may posit people as self-interested individuals who assess a full set of information before making decisions that maximize utility at the lowest cost, but actual decision makers consider others' opinions and approval, weigh other characteristics more highly than cost, and satisfice rather than maximize (i.e., they settle for the first minimally acceptable option rather than weighing all options using multiple criteria). Understanding how people really decide and change requires questioning, observing, and interacting. According to Ch. 18: Carbon Cycle Science in Support of Decision Making, p. 728, researchers and stakeholders must co-produce knowledge.

6.2 Energy Behavior and Embedded Carbon

Although social scientists have investigated the social processes responsible for growth in carbon emissions and decline in the capacity of carbon sinks, enlarging and enriching this knowledgebase would provide better guidance for policy that addresses systems, technology design, and other efforts to reduce overall carbon emissions. In addition to energy production, expansive urban settlements, and transport systems and activities (see Ch. 3: Energy Systems, p. 110, and Ch. 4: Understanding Urban Carbon Fluxes, p. 189), researchers have considered the acquisition and accumulation of goods, as well as their embodied energy and carbon contents. Demand-side research has focused on the technical characteristics and uses of energy-powered devices, in addition to the patterns of energy demand and carbon emissions resulting from the use of buildings and appliances (Sovacool 2014). Economics work aside, the bulk of social

and behavioral sciences research and attention with respect to energy demand has been concerned with encouraging energy conservation and emissions reductions predominantly by individuals and households (Dietz et al., 2009; Stern et al., 2016; i.e., generally, behavior at the level of devices). There has been less attention to the structure and evolution of energy demand and its carbon emissions implications. For example, research on people's role in residential air conditioning has focused on how people use their air conditioning systems and how to get people to use less, rather than on the social processes involved in housing construction, device design, and lifestyles that encourage increased installation of air conditioning in buildings and vehicles.

6.2.1 What Does the Research Show?

In contrast to relating energy use and carbon emissions to devices, social science researchers have emphasized that energy use and carbon emissions are deeply interwoven—"embedded"—features of social life. Energy consumption and emissions are part of people's routines and habits, within patterns of social interaction, and are governed largely by social norms and expectations, without regard for or reference to energy sources or carbon emissions resulting from these activities. Moreover, in North America, although energy infrastructure (e.g., power lines and electrical cords) is visible, energy itself is virtually invisible to people except in special cases (e.g., cooking with a gas flame) or under unusual circumstances (e.g., appliance or system failures, grid blackouts, or energy-supply crises; Nye 2013; Rupp 2016; Shove 1997; Trentmann 2009). Although modern North American lifestyles are constrained somewhat by available energy sources and costs, they have come to represent a set of living standards and desires—normal expectations that exert growing "demands" for easily accessible energy that currently almost always is supplied across long distances and often requires considerable, yet invisible to the user, carbon emissions. Increasing installations of solar microgeneration, discussed below, could shift users' relationships with energy systems to some extent, making the sources and limitations of energy supply clearer. However, if users are to contribute to major reductions in carbon emissions, they also will modify their living standards and daily activities in the name of what they now may see as intangible environmental benefits. Thus, even if emissions were visible and easily accountable, major change would not necessarily occur, unless people see that the benefits will improve their lives in measurable ways.

As noted, both the nature of energy-using behaviors and their susceptibility to change (mostly through formal interventions) have been investigated in studies by researchers and analysts in the energy-efficiency field as well as by social scientists working in other realms. Economics has provided the most generalizable theories of investment decisions and of change (i.e., reduced consumption in response to increased unit price of energy), but the strength of relationships is often quite low (Bernstein and Griffin 2006; Kriström 2008; Lijesen 2007), related to aggregate rather than individual patterns, and compromised by what economics literature identifies as market and nonmarket failures (Jaffe and Stavins 1994).

The other, less-explicit economic explanations for energy-use behaviors and susceptibility to change given so far tend to be general and cannot be readily applied as mechanisms for reducing rates of carbon emissions, ranging from the abstract and macrohistorical (e.g., aggregate conditions and factors such as "affluence," "consumer preferences," and "institutional barriers"; NRC 2010) to the micropsychological (e.g., "motivations," "intentions," "values," "beliefs," and "propensities to adopt"; Shove 2010). These explanations often come with the assumption that actions are driven by these micropsychological properties (Ignelzi et al., 2013; Sussman et al., 2016). The descriptive layers do present ways of "seeing" people as diverse and evolving participants in energy use. Unclear, however, are how and how much the underlying qualities described in these analyses might be deliberately changed and, if they were, whether the desired reductions of energy use and carbon emissions might be achieved.

Leading-edge research has focused on diversity across individuals and households and on the layered structure of this diversity as opposed to simpler explanations rooted in isolated choices, with a particular emphasis in recent literature on populations, practices, patterns, and behavioral economics.

- Observed energy-use levels vary dramatically across populations (e.g., households or firms) due to differences in activity patterns, technical efficiency, and environmental conditions. Energy-using activity patterns are shared within groups, and different groups may have widely varying patterns of activity and modes (Lutzenhiser et al., 2017; Sonderegger 1978).
- Activities and practices, many involving energy-using equipment, emerge and are elaborated over time; some decline while others persist (Shove et al., 2012) as people modify and adapt physical systems to better meet social and cultural purposes and, in turn, modify what they do as they are "recruited" by and adopt practices (Shove et al., 2012).
- Patterns are stabilized and constrained by the characteristics of their energized technologies and infrastructure, much more so than being clusters of discrete personal behavioral choices (e.g., Shove et al., 2012).
- Insights from behavioral economics may be useful in designing instruments for energy-related behavioral change (Allcott and Mullainathan 2010) by focusing on the microstructure of decisions.

However, the complex and nuanced dynamics of energy use are not reported with much clarity in the literature. Future research could focus on understanding what influences the self-organizing nature of daily activity rather than directly engaging individuals and their behaviors.

Reviews find no overarching theory or set of consensus research methods (Lutzenhiser 1993; Wilson and Dowlatabadi 2007) and no cumulative practical understanding of "what works." Instead, there are compartmentalized disciplinary knowledgebases guided by divergent perspectives and distinct methodological preferences. In the area of applied research, narrow perspectives of program- and policy-centered research have focused on the efficacy of specific interventions or instruments, finding that certain actions may be more amenable to intervention-based change within some groups (Abrahamse et al., 2005; Ehrhardt-Martinez and Laitner 2010). Applied research on energy-conservation actions, such as equipment purchase decisions, has long been dominated by short-term policy objectives (such as responding to demand or meeting utility-savings goals) even as these goals are increasingly translated to the longer timelines of supply planning and climate change. Energy use is represented typically as averages and norms, making calculations and planning appear more tractable but generally hiding the dynamic sources, forms, and logics that create energy use.

Programs and projects that focus on or pay attention to "behavioral energy-savings potential" usually are not connected to relevant insights and framings from the social sciences or accompanied by serious considerations of how this potential might be achieved. (For a history and critique, see Wilhite et al., 2000.) These programs typically focus on discrete actions relative to assumed normative behavior—parallel to notions of technical potential via efficiency—rather than attending to how behaviors are organized (e.g., as addressed by social practice theory; see Section 6.9, p. 282). Thus, they miss opportunities provided by recognizing how systems, rather than individuals, create energy use. The findings of behavioral analysts have been used in experiments and case studies on behavioral economics (Ariely 2010; Alcott and Mullainathan 2010; Alcott and Rogers 2014), concept of "influence" (Cialdini 2010), social marketing (McKenzie-Mohr and Smith 2007), primary motivations (Pink 2010), and "nudges" (Thaler and Sunstein 2009). But that use has been without broad influence on programs and projects (Frederiks et al., 2015). Interestingly, behavioral economics experiments have found that economic incentives

and awards are weak motivators compared to, for instance, friendship ties (Ariely 2010).

Given the calls for absolute reductions in greenhouse gas (GHG) emissions rather than relative savings from energy efficiency, there is a need for a broader multidisciplinary social scientific and applied view (Keirstead 2006; Lutzenhiser et al., 2017). However, efforts to identify theoretically grounded and evidence-based "design principles" for carbon-reduction interventions are just beginning (Stern et al., 2016). Three factors hamper such efforts: 1) the absence of a systematic social science carbon-reduction research agenda, 2) the lack of adequate support from science and environmental policy agencies for social science contributions as a core component of energy-transition and carbon-mitigation research, and 3) insufficient experience in drawing together disparate scientific perspectives to address such complex high-level problems. Programs that are beginning to integrate scientific perspectives include those discussed throughout this chapter; findings from such programs are reiterated in Section 6.11, p. 285.

6.2.2 Learning from the Energy-Efficiency Experience

A good deal of the research on energy use to date has been the result of U.S. federal, state, and local policy initiatives to encourage energy efficiency (Lutzenhiser and Shove 1999). Those initiatives have recognized since the 1970s that "energy services" such as cooking, washing, heating, and cooling could be provided via technologies that, technically at least, consume much smaller amounts of energy than then-current models (e.g., Gillingham et al., 2006). Thus, public policy has focused on increasing the efficiency of appliances and buildings to displace a fraction of current consumption and delay the need for new sources of energy. Emissions reduction can be a co-benefit of energy-efficiency improvement. However, differences between efficiency improvements and reductions in absolute emissions over time are easily overlooked.

Also, because interventions to improve the energy efficiency of technologies have been funded largely by utility ratepayers under the scrutiny of public regulators, the primary focus has been on hardware upgrades and "cost-effectiveness"—not on energy users or their habits, desires, or social practices. The kinds of research needed to support these efforts have been engineering studies and economic cost-benefit analyses. Emphasis has been placed on energy cost savings.

However, behavioral science research related to interventions has shown that energy demand is not particularly price sensitive (Kriström 2008). This research has pointed to the importance of environmental values, social influences, and concerns for others as more frequent and actionable motivations for carbon-reducing equipment purchases and energy-use behaviors (Abrahamse et al., 2005; Stern et al., 2016).

Large "efficiency gaps"—gaps between predicted rates of economically attractive purchases of more efficient technology and actual realized adoption rates—have been reported regularly (Allcott and Greenstone 2012; Gillingham and Palmer 2014; Jaffee and Stavins 1994; Shove 1998). In short, energy appears to be an area where markets do not function as predicted by rational economic behavior as envisioned by classical economics—or these definitions are too simple, and there are inadequate data and understanding to represent sufficiently the complex decision processes. Programmatic explanations point to "barriers" to efficiency program participation (Golove and Eto 1996). Lists of barriers (e.g., "high discount rates" or "risk aversion") often are labels or glosses that say more about policy perspectives and program priorities than the nonadoption behaviors of actual energy users or their relationships to the energy uses targeted for change (Blumstein et al., 1980). Also, recurrent questions have been raised about "rebound effects"—the case in which expected savings from technology adoption may not be realized because of choices, behaviors, and intervening developments not predicted by efficiency-intervention planners (Gillingham et al., 2016; Herring 1999). In addition, traditional definitions of energy efficiency are

not necessarily closely aligned with issues related to carbon emissions because not only do they not take into account the carbon content of supply, they focus on relative savings rather than absolute emissions (Moezzi and Diamond 2005). More recently, scholars have stressed the importance of the "macrorebound" of carbon and energy in a growth economy (Wilhite 2016).

Many of the problems with adoption of efficient technologies can be traced to the existing situation. Regulatory logics and institutional constraints push the energy-efficiency industry, itself a socially structured enterprise, to assume that choices made by energy users are well informed and economically rational (Lutzenhiser 2014). This assumption has encouraged efforts to improve the quantity and quality of information available to energy users, with an emphasis on communicating the economic benefits of energy savings. But psychological research has shown that the "delivery" of information is far from a simple matter and that even the highest-quality information supplied as directly as possible, whether via old media or new, frequently is not acted on in the way that program developers imagine that it should, or would, be (Owens and Driffill 2008; see Section 6.10, p. 284). Even well-informed social actors routinely pass over clear and simple "rational" choices that would save money by saving energy.

This disconnect between assumptions and outcomes is as true for large firms and governmental agencies that have sophisticated information systems, analytic capacities, and strong economic interests (Biggart and Lutzenhiser 2007) as it is for individuals, households, and other groups. Explanations point to organizational structure, competing priorities and internal conflicts, risk and trust issues, and weak regulation (Stern et al., 2016). However, there also are instances of organizations leading the way in carbon reduction through corporate investment in renewable energy sources, supply-chain efficiency improvements, and energy-conscious acquisition and operation of buildings and other capital equipment (Prindle 2010; Stern et al., 2016). Research to determine how organizations variously relate to and manage carbon emissions, often in ways that defy simple explanation (e.g., by reference to cost and benefits, regulatory influence, or competition) is in its initial stages.

6.2.3 Expanding the Efficiency Policy Framework: Insights about Energy and Social Systems

Evidence suggests that various energy-efficiency technology innovations and policy initiatives undertaken over 40 years of activity in this field have saved energy (e.g., NRC 2001). However, the narrow regulatory focus and underperformance of these innovations and initiatives relative to idealized models, as discussed above, reinforce the importance of moving beyond a traditionally narrow energy-efficiency industry focus on producing energy reductions at less cost than supply (Lutzenhiser 2014). Future research and institutional changes need to recognize the social nature of energy use—including the social organization of technologies and energy systems, the social patterning of energy demands, the social nature of energy-conservation choices, and the social delivery of energy-efficiency programs and policies.

Although these social issues have rarely been explicitly considered in energy-efficiency policy or associated research, the "market transformation" strand of efficiency intervention is an important exception and success story. These activities are aimed at "upstream" actors and organizations in supply chains that engage with technology designers, manufacturers, wholesalers, and retailers to encourage, facilitate, and provide financial incentives for bringing more efficient technologies to the marketplace at appealing prices (Blumstein et al., 2000). Also, efforts by some states and the U.S. federal government to regulate the energy-using characteristics of appliances and buildings through codes and standards have had wider systemic impacts on technology efficiency. These upstream changes to improve efficiency have occurred despite strong political opposition from an array of groups and interests holding stakes in existing technologies, infrastructures, and supply arrangements (Sovacool 2008). Considerable social science research is needed on carbon management

and the market systems, supply chains, and organizational networks involved in shaping and delivering technologies (Janda and Parag 2013).

Several other strands of social research on energy use and conservation also hold promise. One has focused on the considerable variation in energy use across populations and among subgroups of energy users. Utilities and other efficiency industry actors have sometimes identified "segments" of energy users to target marketing and communications to their interests. But these efforts, redefined as the lifestyle dimension of energy—how people's behaviors socially vary and place different loads on even the most efficient energy-using equipment—offer opportunities for a better understanding of the invisible and embedded dimensions of social carbon management. In addition, periodic energy-supply crises, such as the 2001 to 2002 California electricity shortages and the 2008 loss of a substantial fraction of electricity supply to Juneau, Alaska, have provided "natural experiments" that highlight variations in energy use and in people's willingness or ability to conserve. Also shown is the malleability of taken-for-granted practices when supply is suddenly called into question (Lutzenhiser et al., 2004; Pasquier 2011) or general economic conditions worsen such as in the 2007 to 2009 recession (see Ch. 2: The North American Carbon Budget, p. 71). In addition, the past decade has seen a growing appreciation of "behavioral potentials" for energy savings (e.g., in equipment-use patterns and practices). Utility regulators and efficiency advocates have responded by adding the modification of what people actually do with energy-using equipment to the technology-efficiency improvements in their agenda.

Different strategies have been proposed to encourage those changes. A primary focus has been on mass delivery of energy usage–related information enabled by advances in electronic metering and data warehousing. The results indicate some modest aggregate reductions in overall electricity demands (Karlin et al., 2015; Power System Engineering 2010; Todd et al., 2014), even in a number of states where utility regulators only mandated delivery of information to allow persons to compare their usage to that of others (Allcott 2011; Allcott and Rogers 2014). However, these efforts have been limited in depth and aims—at least, when measured against goals—and represent small investments compared to technology-focused efficiency activities.

Despite an explicit linking of behavior changes to climate change by some academic and public-sector actors (e.g., within the Behavior Energy and Climate Change Conference, held annually since 2007 (ACEEE/BECC 2016)), the social sources and logics of energy-using practices, habits, lifestyles, and behaviors, as well as their organization and how they change continue to receive little systematic attention in U.S. scholarship. There is progress, for example, in the biannual European Summer Study on Energy Efficiency and in other efforts to "push the envelope" of energy-efficiency thinking and intervention by augmenting the classic economics framework (Frederiks et al., 2015), but this work tends to be siloed. However, there is valuable experience that can be gained from careful attention to successes and failures of energy-efficiency policy interventions, and that experience can serve as a starting point for broader and more universal carbon-reduction initiatives in the future.

6.2.4 Energy and Carbon Emissions Embedded in Complex Systems

Apart from efficiency, the other main route to reducing emissions from energy use has been developing and fostering lower-carbon energy sources. Human-centered research on this topic has focused on social acceptance of these alternatives. As much higher market shares of renewables start to become realized, researchers have started to pay closer attention to the intermittency and time-variability of renewable energy sources and how supply dynamics can synchronize with energy use rooted in temporal patterns of daily living. The social dimensions of technology acceptance (e.g., rooftop solar and wind farms, among newer technologies; nuclear power, among established technologies) and the social dynamics of routines and demand patterns (e.g., the locus of work and the cultural

definition of approved practices) will require concerted attention in social science research, carbon policy development, and energy system management. These efforts also must contend with the fact that the energetic structure of the modern North American society has developed with the experience and expectation of ready and virtually unlimited availability of energy at any time of day to fuel homes, cars, work, and play in any and all locations (see Ch. 4: Understanding Urban Carbon Fluxes, p. 189, for a discussion of urban forms).

The social-technical-environmental systems and systemic interactions involved in even the simplest energy-using and carbon-emitting human activities are complex and resistant to change via deliberate interventions—particularly on short time scales. And in that complexity, there is a "chicken and egg" quality to the relationships between supply (e.g., of goods, appliances, energy, buildings, vehicles, and transport options) and demand (i.e., for energy services). Demands are shaped and constrained by what is available, and effective supply requires that households and organizations actually consume what is offered. At the same time, suppliers attempt to encourage and increase demand through marketing, while consumers (certainly households but, most effectively, organizations) attempt to shape supply, such as through energy-related choices, regulations, and efficiency requirements. Capturing this complexity to show effective and democratic paths to reduced carbon emissions clearly requires more inclusive integrated models and increased understanding of the systems involved. This need for better models and understanding reflects earlier arguments (Douglas et al., 1998; Meadows 2008) and echoed in recent work on energy and climate change (Labanca and Bertoldi 2013; Shove et al., 2012). This also will require renewed attention to how evidence is evaluated. Next-generation analytic models and policy approaches will need to draw on new collaborations among research disciplines and between the scientific community and the social worlds in which energy is used and carbon is released to the atmosphere.

6.3 Governance and Carbon

A principal focus of climate change research comprises the kinds of governmental targets and timetables, policies, and regulations that will affect people's carbon-emitting and -capturing activities, such as energy production and land management. Social science research has expanded from an early focus on international and national governmental agreements and policies to a broader conception of carbon-relevant governance.

"Governance" refers to the processes and structures that steer society and the multiplicity of actors who are involved in this steering. The focus on governance, as opposed to governments, highlights the multiple channels through which collective interests are now pursued in the "post–strong state" era (Jordan et al., 2005; Kjaer 2004; Pierre and Peters 2000; Rhodes 1996). The complex configurations of processes and actors governing carbon emissions—who governs, with what authority, and through what means—set the context of the social, economic, and environmental costs and benefits provided by these systems (Marcotullio et al., 2014). To understand patterns of carbon emissions and, importantly, how to facilitate sustainable emissions trajectories, researchers and decision makers not only need to understand the governance processes guiding their production, maintenance, and conservation, but also need to identify feasible governance options for reducing carbon emissions.

6.3.1 Methods in Governance Research

Governance researchers use a range of quantitative and qualitative methods to understand both how particular governance arrangements arise and the social, economic, or policy consequences of different governance arrangements (Pierre and Peters 2000). Research also has focused on more normative approaches, including how governance arrangements can be designed to enhance participation and equity, be more democratic and accountable, improve efficiency, or support environmental objectives (Fainstein 2010; Hughes 2013; Pierre and Peters 2000; Sabatier et al., 2005). Increasingly, governance

research is using network-based approaches and theories to understand the complex web of actors and resources underpinning environmental planning and programs (Aylett 2013; Lubell et al., 2012; Paterson et al., 2013; Scholz and Wang 2006; see Section 6.8, p. 282, and Ch. 4: Understanding Urban Carbon Fluxes, p. 189, for a discussion of municipal networks). Governance research is often interdisciplinary, drawing on scholarship from political and policy sciences, economics, public administration, sociology, and geography (Kjaer 2004).

6.3.2 Key Findings from Governance Research

Despite previous calls for research (Canadell et al., 2010), few projects have explicitly examined the governance of the carbon cycle in North America, although there has been some work on carbon in a global context (e.g., Bumpus and Liverman 2008; Lövbrand and Stripple 2006). Rather, research tends to address carbon indirectly through analyses of governance processes and institutions operating at different scales and in different sectors related to climate change, sustainability, resilience, and even energy efficiency (Portney 2013; Wheeler 2008). Governance research increasingly has focused on the subnational level, where many North American states, provinces, and cities have taken the lead in setting ambitious GHG emissions–reduction targets and climate concerns are reshaping policy agendas across issue areas (Bulkeley and Betsill 2003, 2013; Hughes and Romero-Lankao 2014; Rabe 2004; Schreurs 2008; see Ch. 3: Energy Systems, p. 110, and Ch. 4: Understanding Urban Carbon Fluxes, p. 189, for examples of energy and urban governance). Carbon governance research also has a tendency to focus on particular sectors, such as agriculture, transportation, the built environment, and energy systems. (See Ch. 4 for a more detailed discussion of urban carbon governance.)

The work presented in other chapters indicates that energy use and production, urban areas, and agriculture are the key sectors shaping the North American carbon cycle. While scholarship typically engages with these sectors as distinctive governance realms, in reality they overlap and contradict one another in important ways. Urban form, policies, and lifestyles are responsible for more than two-thirds of global energy-related GHGs (IEA 2008), setting the demand for energy supplies and transportation behavior (see Ch. 3 and Ch. 4). Agricultural policies and priorities also shape the energy needs of this sector and, with the rise of biofuel production, can play an important role in facilitating or inhibiting renewable energy goals (Roberts and Schlenker 2013; see Ch. 5: Agriculture, p. 229). Governance research indicates that the governance systems for these three sectors differ from one another and, potentially over time, in three important ways—their sources of power and authority, institutional arrangements, and sets of their stakeholders engaged by governance processes.

Sources of power and authority can vary from more formal (e.g., U.S. federal regulations) to less formal (e.g., customer demand and preferences), and from more local (e.g., municipal governments) to more global (e.g., international agreements). Each sector engages a spectrum of power and authority sources. For example, power over land-use planning is largely local, but the forces shaping urban development patterns run the gamut from local to global (Glaeser and Kahn 2010; Salkin 2009; Stone Jr. 2009). Although U.S. federal agricultural policy plays a large role in setting incentives and policy priorities (Klyza and Sousa 2008), there is no equivalent mechanism for cities (Barnes 2005). Governance also can be driven in a more "bottom-up" fashion, as local actors and organizations seek to challenge prevailing power and authority sources that sustain existing carbon-related practices (Geels 2014; Seyfang and Smith 2007; Shove and Walker 2010).

The institutional arrangements of governance—the sets of rules, norms, and shared practices that underlie decisions—also differ among energy, urban areas, and agriculture. Institutional arrangements vary among these sectors in ways that have important consequences. Institutions may allow for greater or less public participation and engagement

from the private sector. Differences in institutional arrangements have implications for accountability of decision making and the sets of preferences and incentives shaping decision making. For example, accountability in urban governance typically lies with local elected officials—city councils and mayors—while accountability in energy production often lies with private utilities operating under widely varying mandates.

Finally, the sets of stakeholders involved in and implicated by the governance of energy, urban areas, and agricultural systems differ in terms of their priorities and position. Farmers' priorities may be entirely different from—even at odds with—those of regional energy companies or urban planners. Even within the U.S. federal bureaucracy, different agencies operate under very different sets of priorities and occupy very different positions in relation to congressional committees and regulated stakeholders; these priorities and positions may change from one presidential administration to the next. Understanding who governance stakeholders are and their priorities and positions is important for understanding carbon cycle dynamics.

6.3.3 Open Questions and Applications for Carbon Cycle Research

The differences and intersections inherent in these three sectors—agriculture, urban, and energy—mean that the path to understanding and improving governance of the carbon cycle requires knowledge of both the particularities of the different realms and the ways in which they reinforce and undermine one another. In particular, there is a need to incorporate a carbon cycle lens in research on their governance. A key area for future research will be shifting from a focus on individual policy tools (e.g., carbon pricing and energy efficiency incentives) to understanding how governance arrangements (i.e., in terms of their power structures, institutions, and stakeholder sets) shape the carbon cycle by encouraging or inhibiting energy conservation and carbon emissions reductions. Issues of fragmentation (e.g., multiple sources of partial authority) and misaligned incentives (e.g., low prices for energy supplies with large social costs) are likely to be pervasive. Another important area to examine is how emerging climate change governance arrangements (e.g., emissions trading schemes, renewable portfolio standards, urban plans, and land-management systems) interact with energy, urban, and agricultural governance systems, individually and together. Given the policy and political intersections among these realms, a focus on reducing carbon emissions may serve as an organizing force for effective carbon governance.

Despite the differences in how energy, urban areas, and agricultural systems are governed, these systems share a set of governance needs to effectively and sustainably govern carbon. All three systems require adaptability and resilience, coordination among sectors and scales, and a reorientation toward conservation and, ultimately, reducing carbon emissions (Bomberg et al., 2006; Voß and Bauknecht 2006). Research should continue to explore and identify patterns of coordinated governance among these realms and opportunities for greater coordination.

Finally, carbon governance research will benefit from more explicit attention to understanding which governance arrangements perform best according to a range of criteria.

6.4 Carbon Scenarios Embedded in the Future

Scenarios have long been used as fundamental tools to explore alternative future trajectories for the evolution of GHG emissions and atmospheric concentrations. Their development and application have spanned both quantitative and qualitative efforts to anticipate likely carbon futures, capture uncertainty in long-term carbon pathways, and establish alternative visions for the future. For example, over the past 25 years, the research community has developed and used the following as important research tools: 1) Intergovernmental Panel on Climate Change (IPCC) IS92 scenarios (IPCC 1990; Leggett et al., 1992); 2) the *IPCC Special Report on Emissions Scenarios* (SRES; IPCC 2000); and 3) most recently, Representative Concentration Pathways (RCPs; Moss et al., 2010). Such scenarios played

an important role in carbon cycle and global change research through their use as forcings for Earth System Models to estimate future changes in the physical climate system. As such, they have tended to have limited representation of the underlying socioeconomic conditions that generate the physical forcings. For example, the IS92 scenarios and RCPs are limited to concentration and atmospheric forcings of carbon dioxide (CO_2) and other GHGs. The scenarios from SRES, however, were associated with broader qualitative storylines regarding future global development, although the quantitative elements were limited to population and gross domestic product (GDP). Furthermore, the global nature of the storylines limited national, regional, or local articulation of development trajectories (Absar and Preston 2015).

In addition to their use in global change research, scenarios and scenario planning are frequently used within the private sector to explore the implications of alternative future energy, policy, and socioeconomic conditions. Shell is considered a pioneer in scenario planning for energy and climate. In 2013, Shell published *New Lens Scenarios*, which outlined technology and economic pathways to net zero carbon emissions by the end of this century (Shell 2013). More recently, Shell published *Shell Scenarios: Sky*, describing a pathway for delivering on the goals of the Paris Agreement (Shell 2018). Similar scenarios have been developed by other energy companies and trade associations (ConocoPhillips 2012; IPIECA 2016; BP 2018). Similarly, relevant energy and climate scenarios from national and international energy agencies include the U.S. Energy Information Agency's *Annual Energy Outlook* (EIA 2018) and the International Energy Agency's *World Energy Outlook* (IEA 2017).

Recent developments in global change research have recognized the importance of having a richer set of socioeconomic scenarios to better understand the alternative pathways by which societal development can lead to different emissions outcomes (van Ruijven et al., 2014), as well as how development can enable or constrain responses to manage risk inclusive of GHG mitigation, climate adaptation, and sustainable development. To this end, a scenario process complementary to RCPs is represented by the Shared Socioeconomic Pathways (SSPs; O'Neill et al., 2017). The SSPs consist of a set of five narratives that represent different combinations of challenges to mitigation and adaptation as well as quantitative scenarios at the national level for demography, GDP, and urbanization. Together, the RCPs and the SSPs represent the "parallel scenario process" (Moss et al., 2010), which was designed to reduce the time needed to develop scenarios for research and assessment. The RCPs enabled the climate modeling community to proceed with new simulations without waiting for bottom-up development of underlying socioeconomic conditions.

An ongoing process for the global change research community is to further elaborate and extend the SSPs to make them more useful for a broader range of social, economic, and policy research (Absar and Preston 2015; van Ruijven et al., 2014). This has included efforts to develop nested storylines for more regional analyses (Absar and Preston 2015) and to extend scenarios to address public health (Ebi 2013), as well as developing additional quantitative scenarios of other indicators (van Ruijven et al., 2014) such as poverty (Hallegatte et al., 2016). Additional effort is being invested in exploring how the SSP framework can be aligned to the Sustainable Development Goals (United Nations 2015).

A key SSP goal is to provide a flexible socioeconomic scenario framework that can be used by the global change community for diverse investigation and applications across multiple spatial and temporal scales. In particular, by integrating SSPs with RCPs, researchers can explore the development pathways that are consistent with alternative GHG concentrations, the climate implications of those concentrations, and the socioeconomic consequences of climate change, as well as mitigation, adaptation, and development policies (Kriegler et al., 2012; van Vuuren et al., 2014). In addition, opportunities exist to broaden the use of scenarios in global change research to include consideration

for normative questions such as, "What are the futures that various people want?" and "How can they be achieved?"

6.5 Vulnerability and Embedded Carbon

Because carbon is embedded in social, economic, political, and cultural arrangements, people are vulnerable to disruptions in the carbon cycle as changes in it bring changes in these social arrangements. Thus, research that first explicitly connects societal capacities, functions, and activities to carbon and then demonstrates the extent of human vulnerabilities will help to define ways to reduce those vulnerabilities. This is an alternative framing (see Section 6.1, p. 265) to vulnerability research and assessment that developed out of a framing that begins with physical changes to the carbon cycle and to climate and considers physical impacts first. (Using the physical science framing, researchers assess the vulnerability of agricultural crops and systems, species survival, future biodiversity, and ecosystem damage.)

In a framing of vulnerability assessment that investigates the potential for harm to human systems—by climate change and, by extension, the carbon cycle sources and sinks—researchers explore questions about who is likely to be harmed by climate change, how much harm is likely, compared across countries or areas, and the sources of vulnerability (exposure, sensitivity, and lack of adaptive capacity; Malone and Engle 2011). Comparative studies may aim to identify priority areas for governmental or donor investments in adaptation activities, while studies that include stakeholders may outline mitigation or adaptation activities and practices that stakeholders themselves are interested in undertaking.

6.5.1 Methods Used in Vulnerability Assessment

Researchers have used two broad approaches. The first is to select indicators of vulnerability and proxy variables (usually quantitative data) that represent those indicators and then to calculate comparative indices. The second approach is tailored to a locality by convening stakeholders and asking them to identify vulnerabilities, perhaps along with developing adaptive strategies or evaluating those already in use.

Studies have used indicators, case studies, analogies, stakeholder-driven processes, and scenario-building methodologies, sometimes employing mapping and geographic information system (GIS) techniques. These approaches often are combined to improve a given regional vulnerability assessment, and risk assessment is sometimes coupled with vulnerability assessment (Preston et al., 2009).

Stakeholder involvement has been particularly important in improving both vulnerability assessments and the design of adaptive responses (Rosentrater 2010). The community of stakeholders, whether in a village or a much larger region, then identify their community's vulnerabilities and how to address them using scenarios of the future that stakeholders develop based on relevant data, values and priorities, and realistic descriptions of what is feasible (de la Vega-Leinert and Schroter 2010; see Ch. 18: Carbon Cycle Science in Support of Decision Making, p. 728; Shaw et al., 2009; UKCIP 2001, 2005). Stakeholder involvement has been used in Canada (Carmichael et al., 2004) and the United States (NAST 2000) to build scenarios of the future.

6.5.2 Application to Carbon Cycle Research

The techniques of vulnerability assessment are well established, but the carbon cycle typically has not been part of research designs or indicators. Examples of studies that do not specify carbon cycle indicators include global vulnerability studies, in which Canada and the United States usually are ranked as having low vulnerability to climate change, whereas Mexico is ranked as having higher vulnerability (e.g., Yohe et al., 2006; Malone and Brenkert 2009). Also, subnational vulnerability studies identify economic activities and livelihoods directly related to carbon. A study of farming in Arizona (Coles and Scott 2009) showed that farmers have good access to information, notably seasonal climate forecasts, but consistently use proven short-term strategies rather

than take the large risks of changing farm animals or taking on the high cost of wind or solar energy. Furthermore, the assumption of rational decision making "ignores important influences such as tradition, identity, and other non-economic factors" (Coles and Scott 2009). Safi et al. (2012) found that rural Nevadans' risk perception of climate change is not affected by the sum of physical vulnerability, sensitivity, and adaptive capacity, but rather by "political orientations, beliefs regarding climate change and beliefs regarding the impacts of climate change" (Safi et al., 2012). For Mexico, Ibarrarán et al. (2010) assessed vulnerabilities to climate change at the state level, using comparative proxy variables; differences among the sources of vulnerability in the coming decades suggest different strategies for mitigation and adaptation. Ford et al. (2010) assessed the social factors in health-related Aboriginal vulnerability in Canada, finding that vulnerability is affected by poverty and inequality, limited technological and institutional capacity, sociopolitical beliefs, and lack of information. Furthermore, these elements of vulnerability are unevenly distributed among Aboriginal populations in Canada.

Bringing carbon considerations into vulnerability assessments has the potential to improve priorities for activities to address carbon cycle–related issues and the information base from which carbon cycle–related decisions can be made. For example, research into vulnerability that includes the carbon cycle can examine the specific implications of 1) depleted soil carbon and forest destruction in the agricultural sector; 2) the benefits of urban agriculture and methane capture for waste; and 3) the impacts of increased heat-trapping from excess CO_2 in the atmosphere (i.e., excess over what is being captured by plants, the ocean, and other sinks). This explicit inclusion of carbon can help stakeholders, who can more easily track the carbon content embedded in societal activities, as identified in vulnerability studies, than they can the more abstract long-term changes in climate. Understanding vulnerability to changes in the carbon cycle allows specific actions to reduce vulnerability by controlling emissions and capturing or conserving carbon.

6.6 Socioecological Systems and Embedded Carbon

Drawing on the seminal work of Holling (1973) to analyze complex adaptive systems and explore their resilience, researchers define socioecological systems as "nested, multilevel systems that provide essential services to society such as supply of food, fiber, energy, and drinking water" (Berkes and Folke 1998). They seek to answer research questions such as 1) What are the connections and dependencies between ecological and social systems (Berkes et al., 2003; McGinnis and Ostrom 2014)? 2) Why are some socioecological systems sustainable, or resilient, and some are not (Cole et al., 2013; Leslie et al., 2015; Ostrom 2009; Pahl-Wostl 2009)? Binder et al. (2013) describe 10 of the frameworks for conducting research on socioecological systems that include change dynamics, but the common goal is to include both social needs and the elements that create and support ecological production that, in turn, supports human beings. Interlinkages, feedbacks, and dynamics can be represented.

6.6.1 Methods Used to Analyze Socioecological Systems

Researchers who investigate socioecological systems and their resilience employ frameworks and models, often presented in network diagrams with or without multiple levels. Data may be gathered from published research, surveys, and interviews with stakeholders. Studies can be highly theoretical or focused on specific areas or systems. For instance, Cox (2014) analyzed the socioecological system of the Taos Valley Irrigation System in northern New Mexico, finding that the multilevel governance structure and the social networks have made the whole system stable and resilient. The study concludes that many factors "are needed in order to sustain complex [social-ecological systems] over time. Moreover, it is important to understand the relationships among the contributing factors. This complexity and interconnectedness would argue against the highly simplified approaches to environmental and development policy analysis that have persisted in scholarship and practice" (Cox 2014).

6.6.2 Application to Carbon Cycle Research

Applying this approach to an integrated analysis of the carbon cycle–and–human society system results in analysis of carbon as part of the configuration that supports humans with livelihoods and daily living activities. This integrated approach sets up a solution space that includes wider alternatives than those achieved simply by reducing emissions through substituting technical fixes; it can explore co-benefits (e.g., health and efficiency) that could more easily lead to action. Formulating questions such as those about people and the carbon embedded in their lives brings in considerations such as urban design, improved health, more leisure time, simplified life arrangements, and more cohesive communities.

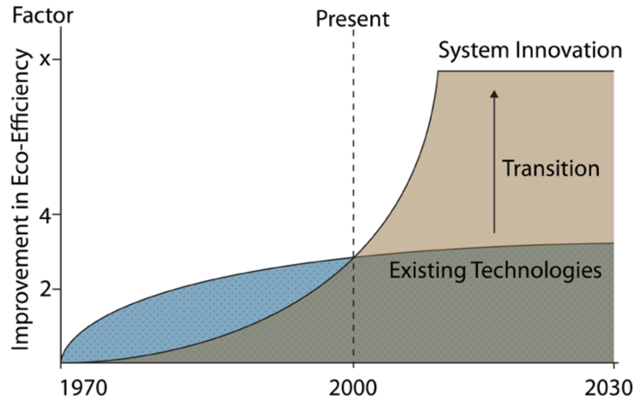

Figure 6.2. Insufficient Improvement of Existing Technologies to Meet Environmental Goals. Greater improvements in eco-efficiency can be achieved through system innovation rather than by system improvement. [Figure source: Redrawn from Vollenbroek 2002, copyright Elsevier, used with permission.]

6.7 Sociotechnical Transitions and Embedded Carbon

Reducing the anthropogenic influence on the carbon cycle implies transformative changes in sociotechnical systems. Therefore, an important issue is to understand why technological change comes about and whether or not change can be steered and accelerated.

The dynamics of sociotechnical changes and possibilities for managing them are studied in the field of sociotechnical transitions. Technologies (including those that use carbon) are deeply embedded in social practices, regulatory and market rules, landscapes, and values; the technical cannot be divorced from the social. This is a dramatic departure from traditional studies of technological change or innovation. One important assumption of sociotechnical transitions research is that greater improvements in eco-efficiency can be achieved through system innovation rather than by system improvement (see Figure 6.2, this page; Vollenbroek 2002). Systems innovation refers to alternative systems of energy, mobility, agro-food, and the closing of material loops (Geels 2002; Grin et al., 2010; Rotmans et al., 2001; Vollenbroek 2002).

Patterns of sustainability transitions are identified by Geels and Schot (2007) and de Haan and Rotmans (2011) and reviewed by Markard et al. (2012). Two foundational models for managing sociotechnical system changes are strategic niche management (Kemp et al., 1998) and transition management (Kemp 2007, 2010; Loorbach 2007; Rotmans et al., 2001). The model of transition management was developed in a project for the government of The Netherlands, based on a science-policy dialogue, details of which are described in Kemp and Rotmans (2009) and further developed by Loorbach (2007).

Transition management seeks to create system innovations through a model of guided evolution. Acting as a process manager, government mobilizes the interests of industry and society in system change with sustainability benefits (Kemp et al., 2007). Transition management methodology comprises the following elements (Meadowcroft 2009):

- Making the future more clearly manifest in current decisions by adopting longer time frames, exploring alternative trajectories, and opening avenues for system innovation, as well as system improvement;
- Transforming established practices in critical societal subsystems within which unsustainable practices are deeply embedded;

- Developing interactive processes where networks of actors implicated in a particular production-and-consumption nexus can come together, develop shared problem definitions, appreciate differing perspectives, and above all develop practical activities;
- Linking technological and social innovation because both sorts of change are necessary if society is to move to a more sustainable pathway;
- "Learning-by-doing," developing experiments with novel practices and technologies because only by initiating change can societies learn the potential, and the limits, of different approaches;
- Tailoring support for technologies to different phases of the innovation cycle;
- Encouraging a diversity of innovations (i.e., variation) and competition among different approaches (i.e., selection) to fulfill societal needs; and
- Assigning an active role to government in mobilizing society to orient change in desired directions.

The visions for the future and details of policy are determined by political leaders, legislative bodies, and voter preferences, not by special agencies. The commitment to long-term change helps to orient state politics more toward system innovation. Government thus responds to calls for change from people and organizations by nurturing new technologies and, once these are better developed, supporting them more actively through diffusion policies. The availability of well-developed alternatives will give policymakers an easier path to introduce policy instruments such as carbon taxes and to phase out carbon-based technologies.

Analytically, the sociotechnical transition perspective examines interaction effects (i.e., coupled dynamics) among actors, technologies, rules, and institutions in evolving landscapes, as the broader context of sociotechnical regimes and niches of radical change. Such interactions give rise to four distinct transition patterns: substitution, transformation, reconfiguration, and de-alignment and re-alignment (Geels and Schot 2007). Specific pathways depend on structural landscape factors that shape action possibilities. Such factors include the presence of a strong and well-organized civil society with active cooperatives, citizen groups, activities, and socially engaged scientists; the salience of environmental issues in politics; and the industrial base for producing eco-innovations—all factors that were stronger in Germany than in the United Kingdom (Geels et al., 2016). In transition processes, no one is in control, and the interaction among different developments gives rise to outcomes that enhance the position of certain actors and technologies. New circumstances and counter strategies from incumbents, however, may change the trajectory.

The sociotechnical perspective emphasizes 1) the centrality of actors, while also being mindful of material aspects (e.g., in the forms of material interests, technologies, and infrastructures), 2) hybrid systems (e.g., decentralized technologies integrated into centralized systems), 3) spillovers from sectoral developments and various policy agendas, and 4) the duality of agency and structure. Attention to niche actors and landscape factors helps researchers to understand the demise of sociotechnical regimes such as in a substitution pathway and their gradual transformation in the three other pathways.

Under transition management approaches, societal interests in alternative technologies and system change are exploited in ways that fit with local circumstances. Transition thinking helps policymakers and actors in society to undertake useful actions in the forms of transition experiments, creation of transition platforms, and use of monitoring systems for managing the energy transition and the transition to the circular economy. These activities complement policies such as carbon taxes, regulations and soft obligations that constitute the Paris Agreement approach (Rajamani 2016), and national sustainable energy policies.

Laws and the embedding of transition endeavors in institutional frameworks help in pursuing transitions but are no guarantee of success. Research indicates that sustainability transitions require both control policies, pursued with rigor and perseverance, and innovation-support policies (Ashford and Hall 2011). Transition endeavors are likely to encounter opposition from incumbent actors, which can be observed in every transition process.

6.8 Carbon Connections in Social Networks

Social network analysis maps the connections among people who have links to one another. The focus is on the nature and strength of the links instead of on any characteristics of the individual members of the network. Examples of links relevant to the research include 1) "gives information to/receives information from," 2) "has a similar worldview," 3) "shares resources with," or 4) "is a coauthor of." Mapping the social network can provide insights about leadership and power structures.

6.8.1 Methods Used in Social Network Analysis

Social network analysis starts with a matrix drawn usually from a survey that shows the links among members of a defined social network. Software is used to both determine and display the linkages found, often with their strength, and to measure such characteristics as important nodes (i.e., centrality), density (i.e., out of the possible links, what is the proportion that actually exists?), and the length of certain pathways (e.g., through how many nodes must information go to get from one person to another?).

6.8.2 Applications to Carbon Cycle Research

Current relevant work, with few exceptions, does not focus on carbon but rather on climate change and disasters. Broadbent studies policy networks in the Comparing Climate Change Policy Networks project known as COMPON (see Broadbent and Vaughter 2014), which has teams in the United States, Canada, and Mexico (among other countries). Armitage et al. (2011) used social network analysis in case studies of co-management institutions for Canadian Arctic fisheries, finding that, over time, these networks co-produce knowledge, drawing on scientific and indigenous sources, that enables learning and adaptation. Malone (2009) used social network analysis to find shared elements of arguments (e.g., worldview, types of data used, authorities used, and solutions proposed) in the climate change debate, finding multiple connections even among analysts who make different arguments. Researchers also have studied disaster-response networks (Kinnear et al., 2013; Robins et al., 2011), where trust is a significant element in coordinated activity. Concerns about carbon link researchers and decision makers in complex networks, but these networks have not been mapped.

6.9 Social Practices and Carbon Configurations

The social practices perspective (Shove et al., 2012) offers a potentially useful approach to the needed "integrated models" discussed in Section 6.2, p. 268. As noted, the focus of U.S. demand-side energy policy has been on improving the efficiencies of devices, with limited attention to energy users, their energy uses, or the social shaping of energy consumption (Lutzenhiser 2014). Similarly, Mexico's Energy Reform program has targeted the technical aspects of equipment, appliances, and energy consumption in public buildings, rather than a more systematic view that starts with a framing of meeting people's needs for energy in low-carbon ways (Valdez 2015).

The social practices perspective takes a more explicit social sciences–based approach to understanding energy use and carbon emissions, offering new ways of seeing complexity and understanding the possibilities for change in social patterns of consumption. Rather than focusing on technologies, behaviors, and desires, for example, as relatively independent, this perspective takes "practices" as the object of inquiry, highlighting how daily living rests on dependencies among people, activities, technologies, and supply

systems, as well as how the various practices relate to each other. It thus involves appreciating the social origins of taken-for-granted "needs" for particular goods and services, which, in reality, vary considerably across time, space, and populations. By not assuming that patterns of activity—human interactions with technologies or current levels of energy use—are fixed or unquestionable, the practices perspective can lead to rethinking housing, transportation, home-workplace relationships, lifestyles, technology designs, and policy approaches.

Social practice theory applied to energy use and carbon emissions draws on several overlapping strands of contemporary research. One strand is sociological theory concerned with how social structures come into being and are reproduced at multiple scales—from the individual to the group, social institutions, and macro-organization within and between societies in the global system (e.g., Giddens 1984). A second is an appreciation that social actors' household habits and routines involve ongoing skilled cultural interactions with technological artifacts and sociotechnical systems (Lutzenhiser 1992). The third recognizes that actors' and households' understandings of their own energy-using activities are important to grasp as they are expressions of larger institutional beliefs and knowledge systems (Shove et al., 1998). Together, the strands focus attention on the systematic interactions among human actors, devices, meanings, skills, infrastructures, and social systems—compared to the more traditional focus on elements in relative isolation (e.g., behaviors, needs, and appliances) that was common in earlier research on energy use and energy efficiency.

Examples of social practices include cooking and eating, driving, walking, riding, using personal and family electronic devices, heating and cooling, washing, entertaining and visiting, and home buying and renovating. While their expression can vary considerably within societies, by definition social practices are not idiosyncratic; they are shared and maintained by social groups. Practices are patterned and clustered with other practices. They often are taken for granted but can become problematic and subject to criticism (e.g., use of water on lawns in drought areas, driving cars short distances for errands, and wearing business suits in the summer in Japan). Practices have histories; they change over time, and they are bundled with physical materials and technologies in mutually supportive relationships. They are sometimes discarded but also can persist long after the conditions that gave rise to them have changed; discarded practices also can be subsequently revived and adapted. In this view, all carbon emissions are produced as a by-product of social practices—and social practices are produced within a complex of social circumstances, rather than by isolated free will.

The importance of beginning research by analyzing these practices to assess the "social potential" (Shove et al., 2012) of interventions in the carbon cycle follows from the fact that, while most energy use and carbon emissions themselves are invisible to the people and groups responsible for them, they are embedded in immediately meaningful social patterns and norms. Therefore, practices often are locked in by shared habits and expectations that require the use of particular devices (e.g., appliances, automobiles, and office buildings) that, in turn, depend on the energy flows and emissions of the larger sociotechnical systems to which they are connected. And these larger systems prove to be incredibly complex, made up of linked technologies and infrastructures, codes and regulations, organizational structures and networks, geographies, and shared scientific and technical knowledge frameworks (Bijker et al., 1987).

Thus, the social practice theory view appreciates this complexity and concludes that what people do with their lives—how they live and relate to others—has considerable salience and importance for carbon emissions reduction, and largely abstract calls for change should be met with skepticism. As a general rule, changes in practices should be expected to be hard to achieve as a policy or market goal, and the hoped-for "levers" of change in practices may well demand coordinated action on interconnected elements of social, technical, political, cultural, environmental, and economic systems. Nonetheless, changes

in practices are continually occurring, sometimes in directions that seem “desired” from the perspective of climate change goals and policies. Funding from European scientific and energy agencies is being directed toward understanding the evolving carbon-emitting practices of households and organizations, with attention to origins, dynamics, interdependencies, and trends—including the effects of innovations in technology and policy on changes in social practice (DEMAND 2016; RCUK 2016).

6.10 The Roles of Communication and Stakeholder Involvement

Although people generally respect science and scientific findings, the so-called science-policy gap persists. The gap appears when scientific findings that seem to call for policy action are not taken up by policymakers in expected ways. Thus, renewed attention has been focused on how to communicate scientific findings to facilitate their enaction. Communicating scientific findings can be ineffective depending on the subject matter, the framing used, and the ways in which messages are delivered. What people choose to believe is heavily influenced by their political environment (Lupia 2013) and by religious or political beliefs (Nisbet and Scheufele 2009). For example, if science reaches consensus on a new rocket technology, there is little question from the public about its legitimacy. On the other hand, if observations and analyses are contrary to political messaging or bring into question belief systems, scientific information can be quickly discounted. Research has been conducted to understand this phenomenon in an effort to identify core issues and a path forward for effectively communicating science.

Initial indications are that cultural and peer-group dynamics are more influential than science literacy and the communication of scientific evidence (Kahan et al., 2012). A follow-up study used a different set of questions to rate “open-mindedness” of individuals and found that the metric only reinforces and accentuates existing beliefs (Kahan and Corbin 2016). Similarly, a comprehensive review of 171 studies from 56 nations found that acceptance of climate change science is more strongly predicted by cultural variables such as ideology and political orientation than by demographic variables including age, gender, income, and ethnicity (Hornsey et al., 2016). More research is needed to understand how individuals assimilate knowledge, particularly if it runs contrary to cultural or peer-group influences. Results from this research might be useful in guiding alternative ways to communicate carbon cycle science results more effectively.

Based on the more recent findings of science knowledge assimilation, frameworks for science communication continue to evolve. New models of science communication have been proposed that would require a coordinated effort to identify questions, conduct research to address the questions, and understand how to best communicate the answers in a robust and supported manner (Pidgeon and Fischhoff 2011). A contemporary definition of science communication outlines specific components that should be addressed when communicating science (Burns et al., 2003). A renewed look at how communication is occurring over social media and how science communication can adapt to the new media landscape has been suggested (Brossard and Scheufele 2013).

Research indicates that communicating consensus around science topics increases public acceptance of the findings, but that a process known as attitudinal inoculation may be needed to maintain acceptance (van der Linden et al., 2017). This process essentially consists of pre-emptively highlighting and refuting false claims and potential counterarguments, such as those made by climate change deniers (Oreskes and Conway 2011). False claims and intentional dissemination of misinformation on related science topics have been analyzed by the research community (Farrell 2016; Supran and Oreskes (2017). A concentrated focus on methods of science communication, based on current understanding of knowledge assimilation, will be critical to enabling the use of science for decision making. Likewise, renewed efforts on making science results more accessible and relevant to collective decision

making, using current communication technologies, are needed.

Many of these research studies examine one-way communication: from scientists to audiences including policymakers, business people, and the general public. Another form of communication, stakeholder involvement—a standard social scientific method—helps researchers and decision makers to address issues and agree on actions (O'Connor et al., 2000; Fiack and Kamieniecki 2017). Mutual exchanges among stakeholders (policymakers and others involved in carbon-relevant decisions) bring to light people's values, concerns, and sticking points and allow dialogue needed to establish feasible options and implement programs. Stakeholder involvement typically identifies co-benefits of reducing emissions; multiple benefits help to gain widespread acceptance. Examples include changes that bring benefits such as reduced air pollution with associated health benefits or new jobs in renewable-energy industries. Other benefits could include amenity improvements from increased urban tree cover, more efficient heating and cooling systems, the convenience of "walkable" neighborhoods, and the safety of buildings that can withstand high winds and flooding.

What may emerge in stakeholder-science-policy dialogues are gradually increasing levels of agreement on issues as well as a variety of options for action. People in direct communication may discover that they are arguing from different viewpoints; missing practical concerns or obstacles; and/or that they actually agree within a mutually defined framing of problems, solutions, or both (Hulme 2009; Malone 2009).

Stakeholder involvement and associated communication exchanges between scientists and decision makers improve the likelihood that pathways forward can be identified, adopted changes will be implemented, and that further changes will be adopted over time.

6.11 Opportunities to Reduce Carbon Emissions

Because changes in social, institutional, and technological structures and practices result from people's decisions to change, the opportunities to reduce carbon emissions are broad-ranging. This section will focus on opportunities for behavioral and institutional changes as described in the research literature.

The IPCC (Blanco et al., 2014) summarized the state of social and behavioral sciences research:

"There are many empirical studies based on experiments showing behavioural interventions to be effective as an instrument in emission reductions, but not much is known about the feasibility of scaling up experiments to the macro economy level. …The net effect of trade, behaviour, and technological change as a determinant of a global increase or decrease of emissions is not established." (Blanco et al., 2014)

Obvious pathways to explore in efforts to reduce carbon emissions are to change individual and group behaviors—for instance, to dial down thermostats, drive and fly less, buy energy-efficient appliances, eat less meat, and plant trees. Dietz et al. (2009) estimated the behavioral potential of these kinds of changes. They found that "the national reasonably achievable emissions reduction (RAER) can be about 20% in the household sector within 10 years if the most effective nonregulatory interventions are used. This amounts to 123 metric tons of carbon (Mt C) per year, or 7.4% of total national emissions" (Dietz et al., 2009). Actions included home weatherization, upgrades of heating and cooling equipment, more efficient vehicles and home equipment, equipment maintenance and adjustments, and daily use behaviors.

Stern et al. (2016) point out that interventions must "take into account key psychological, social, cultural and organizational factors that influence energy choices, along with factors of an infrastructural, technical and economic nature. Broader engagement of social and behavioral science is needed to identify promising opportunities for reducing fossil fuel consumption" (Stern et al., 2016). These researchers then describe short-term, intermediate, and long-term changes that could reduce fossil fuel consumption (FFC). Table 6.1, p. 286, is adapted from a portion of their table that listed actions for

Table 6.1 Changes to Reduce Fossil Fuel Consumption at Various Social and Temporal Scales[a,b]

Social Scales and Roles	Temporal Scales		
	Short-Term Actions (Moments to Days)	**Intermediate Actions (Weeks to Decades)**	**Long-Term Actions (Generational, Transformational)**
Organizations as energy consumers	Induce employees to reduce energy use (e.g., in offices, minimize use of task lights, computers, auxiliary heating and cooling devices). Reduce motorized business travel (e.g., by using video conferencing). Assign staff "energy champion" responsibilities. Manage production systems in response to real-time price signals.	Make reducing fossil fuel consumption (FFC) a strategic part of core business operations. Replace lighting and HVAC systems, equipment, and motor vehicles with energy-efficient models. Rent or procure low-FFC buildings when relocating. Adopt photovoltaic systems. Change work styles to accommodate a broader range of thermal conditions (e.g., Japan's Super Cool Biz program).	Change core business offerings to align with climate challenges (e.g., BP's short-lived "beyond petroleum" experiment, or Interface Carpet's goal of carbon neutrality).
Organizations as providers of goods and services	Find lower-footprint supply sources. Inform customers on how to use products and services offered in an energy-efficient way. Reduce FFC in the production chain.	Make reducing FFC a strategic part of core business offerings. Support and train staff in systems thinking and sustainability. Redesign products for lower energy requirements. Elect to manufacture, market, and service low-FFC products.	Develop lower-carbon, industry-wide standards (e.g., carbon labeling schemes for suppliers).
Large-scale social systems	Improve crisis responses to power outages and fuel shortages.	Adopt policies to encourage and assist lower-FFC actions in households and organizations. Create institutions and norms for lower-FFC actions in groups of organizations.	Improve public transport system. Design communities for easier nonmotorized travel. Change norms for socially desirable housing, vehicle types, workstyles, and work practices.

a) Adapted from Stern et al., 2016.

b) Key: FFC, fossil fuel consumption; HVAC, heating, ventilation, and air conditioning.

organizations (i.e., consumers and producers) and large-scale social systems.

6.12 Conclusions

6.12.1 Research Insights

Findings from these lines of research draw on scientific knowledge about social change, the role of science in societies, multilevel governance, and social-psychological behavior in many settings. The following research findings and insights reflect the people-centered framing discussed throughout the chapter and hold promise for future exploration.

People-Centered Research. Research that is framed to begin with people and explore how various social, political, and economic configurations and technologies have carbon embedded in them reveal points of intervention that are practical and feasible.

Expanded Use of Data. "Big data" and associated data-mining activities related to social segments, lifestyles, and purchasing and activity patterns could significantly expand relevant knowledge about people, social systems, and embedded carbon.

Analysis of Real-Life Decision Making. Understanding how people really decide and change requires questioning, observing, and interacting; decision makers rarely make ideal, completely rational decisions.

Invisibility of Energy and Emissions. Energy consumption and emissions are part of people's routines and habits, within patterns of social interaction, and are governed largely by social norms and expectations—without regard for or reference to (out-of-sight) energy sources or carbon emissions resulting from these activities.

Shared—and Varied—Patterns of Energy Use. Energy-using activity patterns are shared within groups, stabilized and constrained by energized technologies and infrastructure; large variations are seen in different groups, across populations (e.g., of households or firms), and over time as people modify and adapt.

Relative Unimportance of Cost Motivations. Environmental values, social influences, and concerns for others are more frequent and actionable motivations for carbon-reducing equipment purchases and energy-use behaviors than are potential cost savings.

Deeper Understanding of Consumer Behavior. Although the energy-efficiency industry tends to assume that customers are rational in evaluating information, psychological research has shown that even well-informed social actors routinely pass over clear and simple "rational" choices that would save money by saving energy.

Success in Marketing Efficient Technologies. "Market transformation" research has been successful in identifying "upstream" actors and organizations in supply chains and engaging with technology designers, manufacturers, wholesalers, and retailers to encourage and facilitate bringing more efficient technologies to the marketplace at appealing prices.

Codes and Standards for Efficient Technologies. Efforts by some states and the U.S. federal government to regulate the energy-using characteristics of appliances and buildings through codes and standards have had wide systemic impacts on technology efficiency.

Importance of Considering User Behavior. "Behavioral potentials" for energy savings (e.g., in equipment-use patterns and practices) have become increasingly recognized. When planning efficiency improvements, utility regulators and efficiency advocates have added the consideration of what people actually do with energy-using equipment to the technology specifications.

Understanding and Modeling Complex Decisions. Capturing the complexity of carbon-relevant decisions to show effective and democratic paths to reduced carbon emissions could be accomplished through developing inclusive integrated models and increased understanding of the systems involved.

Improved Understanding of Governance Processes. To understand patterns of carbon emissions and, importantly, how to facilitate sustainable emissions trajectories, researchers and decision makers would benefit from increased understanding of the governance processes guiding emissions' production, maintenance, and conservation, leading to identification of feasible governance options for reducing carbon emissions.

Differences and Common Needs Among Governance Systems. The governance systems for the energy, urban, and agricultural sectors overlap and sometimes contradict one another; they differ from one another in three important ways: their sources of power and authority, their institutional arrangements, and the sets of their stakeholders engaged by governance processes. Despite the differences in how these systems are governed, they share a set of governance needs to effectively and sustainably govern carbon—needs to adapt, increase resilience, coordinate among sectors and scales, and reorient toward conservation and, ultimately, reducing GHG emissions.

Broadened Use of Scenarios. Opportunities exist to broaden the use of scenarios in global change research to include consideration for normative questions such as, "What are the futures that various people want?" and "How can they be achieved?"

Systems Analysis to Improve Options for Effective Action. Analysis of carbon as part of a socioecological system that supports humans with livelihoods and daily living activities sets up a solution space that includes wider alternatives than simply reducing emissions by substituting technical fixes; the socioecological approach can explore co-benefits (e.g., health and efficiency) that could more easily lead to action.

Technologies as Embedded in Social Systems. Technologies are deeply embedded in social practices, regulatory and market rules, landscapes, and values; the technical cannot be divorced from the social.

Needs for Both Policies and Markets. Well-developed systems are unlikely to be overthrown by new ones through market processes: sustainability transitions likely will be faster and more comprehensive with strong governmental policies in the form of a phase-out of unsustainable technologies. Research indicates that sustainability transitions benefit from control policies, pursued with rigor and perseverance, next to innovation-support policies.

Analysis of Social Practices. Daily living rests on dependencies among people, activities, technologies, and supply systems and how various social practices relate to each other. It thus involves appreciating the social origins of taken-for-granted "needs" for particular goods and services, which, in reality, vary considerably across time, space, and populations. By not assuming that patterns of activity—human interactions with technologies or current levels of energy use—are fixed or unquestionable, the practices perspective can lead to rethinking housing, transportation, home-workplace relationships, lifestyles, technology designs, and policy approaches.

Two-Way Communication. One-way communication of scientific findings is problematic (especially when people's values or beliefs seem threatened), but well-designed stakeholder involvement can result in mutually accepted actions.

6.12.2 Research Priorities

Carbon is embedded in myriad types of social-economic-political-cultural institutions and thus is involved in the interwoven systems that emit and sequester carbon. Human institutions include government, industry, energy, transportation, buildings, urban areas, land, agriculture, and households. The current state of the carbon cycle is, therefore, an extremely complex, although not intractable problem. Recognizing the social embeddedness of carbon leads to research that will deepen knowledge about how social systems both persist and change, indicating pathways by which carbon emissions can be reduced and carbon sequestration increased.

Although much valuable research is sector based and economically minded, social science researchers have gone beyond these types of research to develop approaches that focus on people and their social configurations—systems of systems—that have carbon embedded in them. This focus is important to assess uncertainties and the progress of mitigation and adaptation efforts. More and more, the challenge of carbon cycle research and management is to deepen basic understanding of how people are negotiating change in their own interests as they live and participate within organizations and institutions, according to constraints, opportunities, and values in specific situations. If people are to contribute to major reductions in carbon emissions, they also will modify their lifestyle choices in the name of what they may initially perceive as intangible or yet-unknown environmental benefits.

The research lines described in this chapter lend themselves both to interdisciplinary research and to stakeholder involvement in development of research questions, priorities of decision makers, and feasibility of proposed actions. Future research needs encompass a spectrum of approaches, as listed below, to increase understanding of people's decision making and change processes.

Theory and Data Gaps. Opportunities to better leverage existing social science datasets or approaches for climate and carbon research include the following:

- *Theory without data.* Potentially useful social science theories—including social survey–based analysis; ethnographic analysis; and narrative sources of insight into people's beliefs, understandings, and actions—have been applied only limitedly to climate change research.

- *Granular data on human activities currently applied almost exclusively for commerce.* In particular, big data and associated data-mining activities related to social segments, lifestyles, and purchasing and activity patterns could significantly expand relevant knowledge about people, social systems, and carbon. However, this potential has not yet been deployed or customized for climate change questions.

- *Data with little or no theory attached.* They include highly aggregated census data and utility billing data, which are common in policy analyses but lack information about users. Social sciences have had only limited involvement in such analyses.

- *Data analysis methods and the evaluation of scientific acceptability.* These approaches are not yet advanced enough to sync with the new worlds of data and types of issues to be addressed.

Recognition of the Social Nature of Energy Use. Future research and institutional changes would benefit from recognizing the social nature of energy use—including the social organization of technologies and energy systems, the social patterning of energy demands, the social nature of energy-conservation choices, and the social delivery of energy-efficiency programs and policies.

Broader Views of Governance. A key area for future research will be shifting from a focus on individual policy tools (e.g., carbon pricing or energy-efficiency incentives) to understanding how governance arrangements (in terms of their power structures, institutions, and stakeholder sets) shape the carbon cycle by encouraging or inhibiting energy conservation and reducing carbon emissions. Issues of fragmentation (e.g., multiple sources of partial authority) and misaligned incentives (e.g., low prices for energy supplies with large social costs) are likely to be pervasive.

Links Among Carbon Management and Other Governance Arrangements. Emerging climate change governance arrangements (e.g., emissions trading schemes, renewable portfolio standards, urban plans, and land-management systems) will interact with energy, urban, and agricultural governance systems, individually and together. Integrated research will represent these interactions.

Technological Transitions. Social scientific research provides better understanding of why transformative technological change comes about and whether or not change can be steered and accelerated in sociotechnical systems to lessen the anthropogenic influence on the carbon cycle.

Social Networks and Practices. Research can map social networks of relevant potential actors in carbon cycle research and mitigation activities and describe everyday practices in which carbon is embedded; both approaches can reveal potential pathways for carbon management.

Use of Existing Tools and Methods. Research that applies such developed methods as scenarios, vulnerability assessment, sociological systems, social network analysis, and social practices analysis to include the carbon cycle will highly complement physical science research by providing understanding of social perceptions of and engagement with aspects of the carbon cycle.

SUPPORTING EVIDENCE

Process for Developing Chapter

This chapter was developed as part of the overall process for initiating the *Second State of the Carbon Cycle Report* (SOCCR2). Although "societal drivers" were specified as a section in all chapters, the Federal Liaisons and Science Leads agreed that a separate chapter on relevant social science research was needed to strengthen the report and respond to the recommendations of the *First State of the Carbon Cycle Report* (SOCCR1). The chapter contents were developed through conference calls and discussions with comments from scientists, U.S. federal agency personnel, and the public.

KEY FINDING 1

Broadened Approaches—A range of social scientific research approaches, including people-centered analyses of energy use, governance, vulnerability, scenarios, social-ecological systems, sociotechnical transitions, social networks, and social practices, complements physical science research and informs decision making. Approaches that are people centered and multidisciplinary emphasize that carbon-relevant decisions are often not about energy, transportation, infrastructure, or agriculture, as such, but rather about style, daily living, comfort, convenience, health, and other priorities *(very high confidence)*.

Description of evidence base

For Key Finding 1, physical scientific research has produced extensive information on the so-called greenhouse effect, the overall warming of the global climate, and the contribution made to climate change by human-caused emissions of heat-trapping gases; studies of the carbon cycle have confirmed that carbon is being emitted to the atmosphere from human activities. Research that starts with this framing has quantified sectors and activities where mitigation of climate change is technically possible. Yet the ideal global policies, national commitments, and implementation of such policies have not taken place to the degree necessary to substantially reduce emissions. Relevant social science research is needed to understand feasible pathways to both mitigation and adaptation actions using a framing that is centered on people. This need has been increasingly recognized by the Intergovernmental Panel on Climate Change (IPPC) and other international, regional, and local organizations concerned with climate change. See Section 6.1, p. 265; Section 6.2, p. 268; and Section 6.11, p. 285, for a more detailed description of the evidence base and relevant citations.

Major uncertainties

Uncertainties include the degree to which societies are vulnerable to climate change, the systematic implications of various candidate actions and policies in specific places, and the capacity and willingness of human institutions and individuals to act.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

Evidence from the existing body of social scientific research has identified feasible pathways to mitigation with very high confidence.

Summary sentence or paragraph that integrates the above information

There is very high confidence in Key Finding 1 that people-centered social science research can explore and demonstrate feasible and implementable mitigation strategies and actions.

KEY FINDING 2

Assumed versus Actual Choices—Planners have assumed economically rational energy-use and consumption behaviors and thus have failed to predict actual choices, behaviors, and intervening developments, leading to large gaps between predicted rates of economically attractive purchases of technologies with lower carbon footprints and actual realized purchase rates *(high confidence)*.

Description of evidence base

From large potential emissions reductions calculated by integrated assessment models to expected behavior changes encouraged by employers, results of first-best policies and programs have been disappointing at levels from the global to the local. See Section 6.2.2, p. 271, for a more detailed description of the evidence base and relevant citations. Even activities such as methane capture, which has been calculated to be economically profitable, have not been widely implemented by mining and other industries. Lifecycle calculations that show savings from energy-efficient technologies such as weatherstripping, insulation, and heating and cooling equipment have failed to prompt rational choices to increase energy efficiency or purchase energy-efficient homes in numbers near the technical potential. See Section 6.2.2, p. 271, and Section 6.9, p. 282, for a more detailed description of the evidence base showing the difference between predicted, economically rational decisions and actual decision-making processes.

Major uncertainties

Although much has been learned about such "market failures" or "barriers," the reasons for gaps between predicted and actual results encompass factors that are still uncertain in their specific roles and magnitudes.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

Numerous studies have conclusively documented gaps between predicted or potential emissions reductions and actual choices and behaviors, leading to a very high confidence level.

Summary sentence or paragraph that integrates the above information

Science findings for Key Finding 2 demonstrate a very high confidence that planners should not assume rational behavior of people and organizations in acquiring more efficient technologies and using them efficiently

KEY FINDING 3

Social Nature of Energy Use—Opportunities to go beyond a narrow focus on the energy-efficiency industry to recognize and account for the social nature of energy use include 1) engaging in market transformation activities aimed at upstream actors and organizations in supply chains, 2) implementing efficiency codes and standards for buildings and technologies, 3) conducting research to understand how people's behaviors socially vary and place different loads on even the most efficient energy-using equipment, and 4) adding consideration of what people actually do with energy-using equipment to plans for technology and efficiency improvements *(high confidence)*.

Description of evidence base

Key Finding 3's four specific areas reflect current research that shows promising results from people-based approaches. Focusing on the systems involved in supply chains—technology

designers, manufacturers, wholesalers, and retailers—brings people and organizations together in a common purpose to facilitate and provide financial incentives to bring more efficient and less carbon intensive technologies and processes into an industry. Similarly, codes and standards for buildings and technologies create industry-wide benchmarks and so encourage sharing of knowledge and practices as well as competition to be efficient or meet a standard such as "Energy Star" (www.energystar.gov). The variations in human energy use by place and social condition have been well established, but people-based research showing why such variations exist and how they can be addressed needs to be expanded and strengthened. When planners include studies of actual energy-use requirements instead of technical potentials, the efficiency gap lessens or disappears—or, in some cases, actual emissions reductions are greater than predicted. See especially Section 6.2.3, p. 272, for a more detailed description of these research studies and relevant citations.

Major uncertainties

Uncertainties arise from the lack of needed social science research in these areas as well as from identifying other areas that would benefit from people-based research into carbon mitigation.

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

There are promising areas of research with positive results in at least four areas of energy efficiency, leading to an assessment of high confidence.

Summary sentence or paragraph that integrates the above information

Promising people-based research covered for Key Finding 3 exists as approaches to increase efficiency and thus reduce emissions along supply chains, implement codes and standards for buildings and technologies, understand the variation in energy use among groups and in different places, and include energy-use practices in planning for new technologies or processes. Thus, a level of high confidence is warranted.

KEY FINDING 4

Governance Systems—Research that examines governance at multiple formal levels (international, national, state/province, cities, other communities) as well as informal processes will identify overlaps and gaps and deepen understanding of effective processes and opportunities involved in carbon management, including a focus on benefits such as health, traffic management, agricultural sustainability, and reduced inequality *(medium confidence)*.

Description of evidence base

As global, "top-down," effective climate change or carbon management policy has proven elusive and likely not to meet goals, Key Finding 4 shows that attention has turned to governance (but not limited to formal governments), including networks, social processes, cultural norms and values, and multilevel steering institutions. In urban areas and agricultural spaces, this research has proven fruitful in identifying insights into how policies are formed and implemented as people pursue their own goals while changing in response to economic, regulatory, and other social changes. Research shows that co-benefits are often important—benefits such as health, traffic management, comfort and convenience, agricultural sustainability, and reduced inequality. See Section 6.3, p. 274, for a more detailed description of governance systems research and relevant

citations. Each place or network or governance arrangement is a complex system, but patterns can be discerned. Analysis of social, technological, and ecological circumstances can lead to tailored approaches and pathways to effective carbon management. See Section 6.6, p. 279; Section 6.7, p. 280; and Section 6.8, p. 282, for more detailed descriptions of the evidence base for Key Finding 4, as well as relevant citations.

Major uncertainties

Uncertainties arise from the diverse circumstances of places and societies. Research may not identify important factors in candidate strategies for carbon management, even with the knowledge that "one size does not fit all."

Assessment of confidence based on evidence and agreement, including short description of nature of evidence and level of agreement

Research confirms the importance of governance. However, because of the complexity and diversity of different societies in different places, and at least the partial lack of research to identify patterns of governance important for carbon management, a level of medium confidence has been assessed.

Summary sentence or paragraph that integrates the above information

Both formal and informal governance are important for the prospects of carbon management. However, variations in social institutions, culture, and values influence the effectiveness of governance. Hence, the difficulties in complex systems analysis bring uncertainty into the prospects for effective carbon management. Thus, Key Finding 4 has been assessed as having medium confidence.

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