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ORIGINAL ARTICLE

Social-ecological system resonance: a theoretical framework for brokering sustainable solutions

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Abstract Sustainability science is a solution-oriented discipline. Yet, there are few theory-rich discussions about how this orientation structures the efforts of sustainability science. We argue that Niklas Luhmann's social system theory, which explains how societies communicate problems, conceptualize solutions, and identify pathways towards implementation of solutions, is valuable in explaining the general structure of sustainability science. From Luhmann, we focus on two key concepts. First, his notion of resonance offers us a way to account for how sustainability science has attended and responded to environmental risks. As a product of resonance, we reveal solution-oriented research as the strategic coordination of capacities, resources, and information. Second, Luhmann's interests in self-organizing processes explain how sustainability science can simultaneously advance multiple innovations. The value logic that supports this multiplicity of self-organizing activities as a recognition that human and natural systems are complex coupled and mutually influencing. To give form to this theoretical framework, we offer case evidence of renewable energy policy formation in Texas. Although the state's wealth is rooted in a fossil-fuel heritage, Texas generates more electricity from wind than any US state. It is politically antagonistic towards climate-change policy, yet the state's reception of wind energy technology illustrates how social and environmental systems can be strategically aligned to generate solutions that address diverse needs simultaneously. This case demonstrates that isolating climate change—as politicians do as a separate and discrete problem—is incapable of achieving sustainable solutions, and resonance offers researchers a framework for conceptualizing, designing, and communicating meaningfully integrated actions.

Keywords Knowledge to action · Transformational sustainability science · Climate-change communication · Wind energy · Renewable portfolio standard · Macro-level theory

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Introduction: mind the gap

A central antagonism addressed by sustainability science is the gap between scientific knowledge and action in sustainability. This gap involves having the technology to transition towards sustainability but not the social, political, or economic capital to implement known solutions. Agyeman (2005) labeled it the sustainability gap stating that "in almost all areas of sustainability, we know scientifically what we need to do and how to do it, but we just are not doing it" (Agyeman 2005: 40). This gap between our scientific understanding of the scale of global environmental challenges and the social and political responses actually embraced in response to this understanding seems to grow ever wider (Crompton and Kasser 2010: 32).

Criticism of the gap has been a productive site of interrogation (Roux et al. 2006; Cash et al. 2006; McNie 2007; Nisbet 2009; Pidgeon and Fischhoff 2011; Clark et al. 2016). The gap, is in part, the inspiration behind the development of sustainability science and the articulation of the need to better "link knowledge with action" (Clark and Dickson 2003; Clark 2007; Reid et al. 2016; Hall et al. 2012a; Braun-Wanke et al. 2015; Cvitanovic et al. 2015; Mattson et al. 2016).

The assumption is that when research is designed with transformation in mind, science can meaningfully engage sustainability problem solving and those communities in need of solutions. This looks differently "to a considerable degree in structure, methods, and content from science as we know it" (Kates et al. 2001: 641). While sustainability science trains students to engage in sustainability problem solving (Wiek et al. 2011) for conducting solution-oriented research (Sarewitz et al. 2012; Miller et al. 2014), there is less attention to characteristics of a "solution"; what are researchers looking for in a solution? What can integrate ecology with a socially robust system description that engages the socio-cultural realms akin to how people experience the world (van Kerkoff and Lebel 2006; Caldas et al. 2015; Hall et al. 2014; Hall and Lazarus 2015)?

This essay proposes an image of social system functioning that may help broadly conceptualize the characteristics of a solution in sustainability science. We use the social theory of Luhmann (cf. Luhmann 1995); a student of Talcott Parsons, who introduced systems theory to sociology. Luhmann's macro-level social theory departs from his predecessors' social stratification theories (of Marx, Weber, Mills, etc.) (Murphy 1982). Luhmann builds his theory on functional differentiation—how society organizes itself by its actions and how these become self-reinforcing (Luhmann 2000). For our purposes, a functional view of society (a) offers language well-suited for integrating social and ecological system functioning into useful system representations for sustainability science problem solving (e.g., for decision making) while (b) accounting for a fundamental principle behind human action—identification; the role of identity in motivating and coordinating human behaviors (cf. Burke 1969). This functional perspective on society is also (c) useful for explaining how societies become aware of ecological problems and (d) thus how social systems can react by aligning multiple sectors of society into sustainable solutions.

In the following, we discuss the call for science to engage in research, which yield solutions to sustainability challenges, then introduce Luhmann's social theory as a means to account for social system functioning, explain the central concept of resonance, and provide an example of how resonance played a role in the development of renewable energy policy formation that has led to the largest renewable energy production of any US state in the unlikely oil rich and openly hostile to climate-change politics of Texas, USA.

A sustainability solutions-oriented field

Sustainability science, as a field of research (Bettencourt and Kaur 2011; Kajikawa et al. 2014), is an interdisciplinary applied science. It is motivated by understanding (1) human–nature interactions within complex social-ecological systems, (2) social transitions towards sustainability, and (3) generating use-inspired knowledge for problem solving (van der Leeuw 2014; Clark et al. 2016; Mattson et al. 2016). It is problem oriented and defined by its ambition to find solutions that transition society towards sustainability (Kates et al. 2001; Cash et al. 2003; Clark 2007; Jerneck et al. 2011; Miller et al. 2014). To operationalize this, it is said to have a dual mission (McGreavy and Kates 2012) consisting of two modes (Wiek et al. 2012). In the descriptive mode, research is conducted to form an understanding of the relations between the social and biophysical systems within a problem setting (Kates et al. 2001; Kates 2011); and then, the transformational mode leverages this descriptive-analytic understanding to intervene in the problem setting to improve it (Wiek et al. 2012). Transformational sustainability science interventions are treated as experiments (Evans et al. 2016; Withycome-Keeler et al. 2016). Rooted in discourse for science to become more responsible and applicable to society (Funtowicz and Ravetz 1993; Lubchenco 1998; Gibbons 1999, 2000; Nowotny et al. 2001; Jasanoff 2003; Latour 2004), the transformational mode of sustainability science is the call for researchers to engage with communities in practical problem solving: the translation of knowledge into actionable solutions (Clark and Dickson 2003; van Kerkhoff and Lebel 2006).

Research designed to transform society constitutes a significant departure for much of Western science (Kates et al. 2001). It effectively changes the purpose of science from pure understanding to knowledge for intervention. Insofar as sustainability science changes the purposes of scientific practice from "pure" a-contextual understanding to context-specific understanding for the sake of intervening towards solutions, it forces new metrics for assessing scientific work. Rather than a search for universal truths, research seeks to discover what works (Flyvbjerg 2001; Sarewitz et al. 2012), what is well composed (Latour 2010), or what is salient, credible, and legitimate (Cash et al. 2003; Clark et al. 2016) for particular settings and the sustainability

Table 1 Niklas Luhmann's (1989) major function systems and organizing logics

Function system	Organizing logics or codes
Economics	Profit/loss
Politics	Government/opposition
Science	Truth/falsity
Law	Legal/illegal
Education	Better/worse
Religion	Transcendence/immanence
Culture	Norm/taboo

challenges therein. Assessing sustainability science is then a reflection of how well the products of research adhere to the real world for addressing problems: the usability of knowledge.

Knowledge of biophysical systems is relatively stable and scalable for problem solving models when removed from social and cultural drivers. For human systems, principles useful at a large scale may be inappropriate for the scale at which human actions change. Thus, designing solutions benefits from in-depth understandings of the interests involved and the normative dimensions at work within particular social systems (Wiek et al. 2011; Whittemore 2013; Polk 2014) as collective action is more likely to occur, and be effective, when consistent with the self-interests of affected individuals (Wilson et al. 2007; McDonough and Braungart 2013). Understanding social systems at a scale usable for action requires engaged field research, informed by and in collaboration with insiders if sustainability scientists are to design solutions consistent with the interests of those who are expected to enact and implement sustainable pathways (Norton 2005; Norton and Thompson 2014; Hall et al. 2012b, 2013, 2016). The coordinated and strategic alignment of stakeholder interests, economic preferences, politically safe spaces, scientifically tested, accepted, and teachable facts contributes less disruption to cultural mores; this enables actions that transform social-ecological systems towards sustainability.

Luhmann's function systems theory

Luhmann's social theory describes society as a series of self-organizing function systems (Luhmann 1989, 1995, 2000). Systems, for Luhmann, are functionally defined as chains of related events or operations (Luhmann 1995, 2012). The most authoritative function systems that constitute society are the economic, legal, educational, political, religious, and scientific function systems. Each of society's function systems operates according to a logic of what is meaningful to that system. These logics are the organizing principles of the system; they are the values that condition a system's autopoiesis allowing the system to distinguish what is meaningful information or not. For Luhmann, these organizing meanings are expressed in binary codes (Table 1). For example, science operates according to a code of truth and falsity. The work of science involves distinguishing truths from falsities. Although the organizing codes are generic at this large scale (e.g., businesses are organized by logics of profits and losses), this level of generality allows for consistency and order across function systems.

The organizing logic of each function system effectively differentiates itself from other function systems within society. This alterity provides identity to the function system; it clarifies membership. For example, business operating within the economic function system is differentiated from other function systems, because they organize actions around a commitment to profit and avoid losses. Effectively, each function system is organizationally closed (Luhmann 1989), where activities within each function system are focused on the system's own reproduction and maintenance.

Luhmann's account of society's function systems illustrates how the natural environment remains separate from society's functional operations. In Ecological Communication, Luhmann (1989) is particularly interested in (1) society's ability to listen to its natural environment as well as (2) the different social systems' capacities to respond to ecological problems. Because society is organizationally closed, each social function system can only respond to its environment according to its own organizing structure. Therefore, a system's capacity to consider ecological factors must be translated into the appropriate value-specific logics of a particular function system. For example, when a drought affects crop yield raising the commodity's price, this disturbs company's profits, thus businesses within the economic function system respond to an environmental factor if it affects profits.

Luhmann's social theory offers a specific articulation of how human and natural systems are coupled. Signals from the environment cannot be heard by society's function systems unless ecological signals interrupt what is internally meaningful to a particular function system. When this occurs, Luhmann calls the ecological disturbances to society "ecological communication". It is only when ecological communication causes an irritation that interrupts economic, legal, scientific, religious, educational, or political operations that the environment comes to the fore and must be managed. More often, the natural world remains hidden from much of society's attention. The closed nature of society's social systems explains why social systems only couple to the environment at specific points. This account also sheds light on why environmental discourse is often crisis-laden, storied with disaster (Shellenberger and Nordhaus 2005) in an attempt to disrupt normal functioning—business-as-usual. In this sense, environmental policies can be viewed as conditioning an appropriate level of irritation or disruption of a social function system to force a change in operations. This would be an ecological communication. For example, one of the world's most powerful policy irritants of the economic, legal, and political function systems is the United States' Endangered Species Act which disrupts several function systems' logics and forces changes in everyday actions (Salzman and Thompson 2014). Social systems only become aware of how they are coupled to environmental systems at points, where the environment communicates with—disrupts—the value logics that organize social functioning.

Resonance

The environment receives the most attention when it impinges on the value logics of multiple function systems. When ecological communication occurs across multiple function systems, Luhmann (1989) describes this notion as resonance. Resonance is environmental stimulation that impacts several structurally differentiated function systems; it is an improbable occurrence because of the closed nature of function systems. Resonance accounts for the relations among society's function systems (e.g., why it is difficult for scientific facts to gain traction in political or religious systems and vice versa) and their relationships with the environment (e.g., why some risks are viewed as salient within economic systems and other risks are not).

In exceptional cases, environmental problems are capable of affecting multiple social systems, resonating within society's closed systems. Internally produced noise of the self-important social functioning is often too loud to hear external signals unless resonance becomes strong enough to impede multiple systems. A rare example of system resonance is the conglomeration of events that simultaneously disrupted several function systems in transformative ways in the 1960s: Carson's Silent Spring (1962) caused perturbations that rippled across several function systems. In the scientific function system, recognition of the impacts of relatively new widespread application of chemistry was shown to have an impact on the ecology of wildlife that cultures appreciate. The popularity of the compelling account of science reverberated into the political realm of those concerned about human well-being and quality of life. This ecological communication (disturbance) unsettled the profit security of chemical manufacturers of DDT and related chemicals. The potential liabilities resonated the legal system into action as well as the political system to regulate the use of new chemicals. The sudden awareness of the environment by society's function systems illustrates that "through resonance small changes in one system can trigger great changes in another" (Luhmann 1989: 117). Under Luhmann's functional view of societies, lasting and substantive social change requires simultaneous resonance, or synergy, among these social systems (Peterson et al. 2010).

It is this notion of resonance that offers a means of communicating what a sustainable solution is and the work needed within the transformational mode of sustainability science to design pathways to solutions. The key question becomes "how society structures its capacity for processing environmental information" (Luhmann 1989: 32).

A sustainable solution: resonance in texas renewable energy policy

In the United States, efforts to enact comprehensive national climate-change policy or low-carbon energy policy have largely failed. In lieu of federal policies, municipalities and states serve as the most innovative jurisdictions for developing climate-change-mitigating policies and supporting renewable energy deployment (Fischlein and Smith 2013). In the following, we provide an example of how a few social actors orchestrated the originating policy of a sustainable solution that achieved resonance across multiple function systems within Texas, a US state known for its hostility towards climate-change science and policy. Texas now produces more wind-generated electricity than any US state (AWEA 2016).

A diverse group of climate-change-conscious policy interveners strategically organized to pass a renewable portfolio standard (RPS)—a policy tool that creates a rule requiring a percentage of a jurisdiction's electricity generation or an amount to be sourced from renewable sources. Strategic actors positioned the policy to resonate by leveraging local understanding of how each system's value logics were expressed to frame a targeted communication campaign about a policy that appealed to the values, desires, and anxieties of key decision makers.

Policies alone do not guarantee the deployment of renewable technologies (Stephens et al. 2008, 2014). Deploying clean energy technology requires actors shaping the capacity for resonance across the interests of the social function systems amenable to the particularities of the industry and the particularities of a place and its people. Resonance is achieved when an ecological communication reinforces the coded logics of most dominant function systems while affirming the identities of local actors within each function system. Sustainability interventions disrupt social system functioning to encourage awareness of ecology while still appealing to and reproducing value logics.

We illustrate this in the following sections using the voices (verbatim quotes from interviews) gathered by in-depth interviews with 25 energy policy interveners in Texas to tell the story of the events leading to this policy's formation and the uptick of wind energy industry that followed in Texas. We define policy interveners as elite actors who influence policy [e.g., energy lobbyists, lawyers, state legislators, utility planners, industry consultants, executives, and non-governmental-organizations (NGO) staff]. Texas policy interveners were identified as those who actively shaped RPS legislation, and an additional provision (rider) added to the Texas electricity market deregulation bill (TX SB 7, 1996). Participants were identified by attendance records from the hearings and snowball sampling. Interviews lasted approximately an hour, they were transcribed, and the content analyzed using an a priori codebook in the QSR's NVivo qualitative analytic software (for a full description of methods see Feldpausch-Parker et al. 2010; Fischlein et al. 2010; Chaudhry et al. 2013). The interviews are part of a larger study investigating how policy interveners, news media reporting, and public discourse converge to shape climate-change-mitigating energy policy within state contexts of Massachusetts, Minnesota, Montana, and Texas (cf. Stephens et al. 2008; Fischlein et al. 2010, 2014; Chaudhry et al. 2013; Feldpausch-Parker et al. 2013).

Texas is an oil state

In Texas, the political environment has been historically hostile to policy efforts to mitigate climate change (Swofford and Slattery 2010). Climate-change policy threatens an economy built on fossil fuel that has the highest total greenhouse gas emissions of US states (EPA 2015 Clean Power Plan Data, 30 August 2015).

> "[Climate change] is a bit of a pariah term. You wouldn't really ever try to push anything in Texas based on climate change and reducing carbon emissions, which means you're reducing carbon fuel use... Texans don't generally like to reduce the use of carbon; which is really our single biggest business. It's really tough to get people excited about that" (TX 12).

It is no surprise that political leadership has denied anthropogenic climate change. "The policy leadership in Texas, has pretty much across the board said, 'Climate change does not exist'…it seems like they'd rather spend time making fun of climate change rather than sort of dealing with it" (TX 09).

> "You know, there's always this undertone that [climate change] is really made up by a bunch of crazy green folks. We all know it's not really real. I mean, there is a whole lot of that in Houston. Houston is an oil town. Texas is an oil state" (TX 18).

Yet, today, Texas generates more climate-change mitigating electricity from wind energy than any other US state with 17,710 MW installed by 2016; three times more than state of California with the most progressive renewable energy policies (AWEA 2016; Fig. 1). Texans love to tout the industry's success and how quickly they accomplished it, particularly in comparison with other states. "Texas has made some things happen extremely fast relative to everyone else in the country with wind. And even though some of them have their rhetoric, their talk is better, they're not getting the results" (TX 12).

Most Texans credit this success to a deregulated "free market" for electricity. Yet, policy interveners tell a more nuanced story. They say, "Texas got the policy right" at the right time, and engaged in "some of the best organizing that's been done in the environmental movement in Texas" (TX 01). The organizers who ushered the "right policy" to law were advocates for mitigating climate change who were successful in aligning a policy rider with the value logics of economic, cultural, political, and legal social function systems in Texas.

"Some 18-year-old kid" and profit potential

According to one participant, the origins of wind energy in Texas began with an ordinary event in the mid-1990s. An 18-year-old kid home from college on Thanksgiving vacation 1 year said to his father, "Dad, we gotta do something about air pollution. We gotta do something about global warming and you got enough money to do something. Let's create a wind company" (TX 01). That young man's father was a billionaire businessman from Dallas.

> "His dad looked at him and said, 'What?!' But he looked into it and decided that, by God, he wanted to create [name of renewable energy company]. And so, all as a result of—you know—some kid on Thanksgiving vacation, [the dad] looked into how much pollution was coming from power plants and realized it was a third of the pollution in Dallas and said, 'This is something that's entirely avoidable. The pollution's gotten much worse in my lifetime. My kid's right. There's a future in wind. Let's make money off the deal.' Turns out, he was George W. Bush's largest contributor and he could get his phone calls answered by George Bush any time of the day or night" (TX 01).

This politically powerful businessman connected with a group of policy interveners who were interested in mitigating climate change during a critical moment of statewide

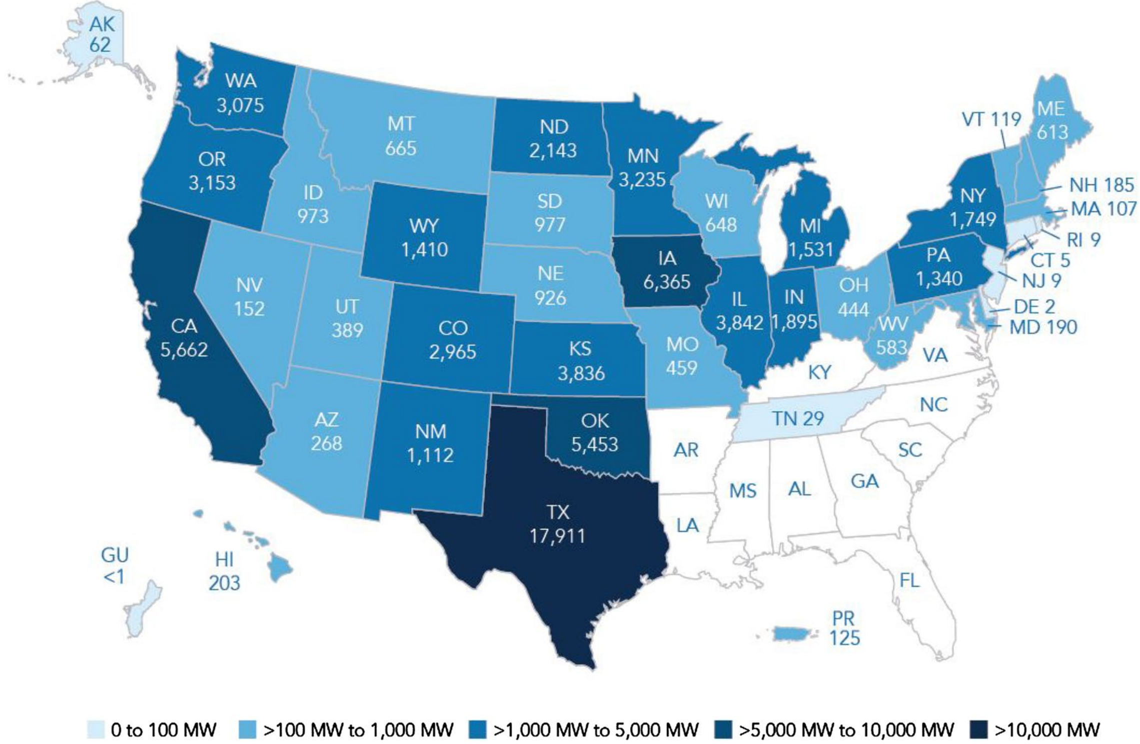

Fig. 1 US wind power capacity by state. Source: AWEA US Wind Industry Second Quarter 2016 market report

efforts to reorganize Texas' regulated electricity market into a deregulated market. Under discussion in the Texas Legislature was Senate Bill 7 (SB7) written to restructure the electricity market. The objective of this group of diverse yet compatible interests was to get renewable electricity generation into SB7.

> "In 1998, basically, five people sat around in a café in Dallas and figured out how to put enough pressure on two members of the legislature to get them to be champions. One of them later turned out to be the person who actually wrote the renewable energy portfolio standard" (TX 01).

To get the support of key legislators, they crafted messaging that framed wind energy as an economic development opportunity aimed at powerful long-term West Texas politicians, whose constituents were experiencing economic hardships from a waning oil boom in the 1970s. Policy interveners were careful to avoid indiscriminate rural economic development. If rural economic development was the message, then why not simply promote more traditional forms of electricity generation, such as natural gas, coal, or nuclear? They had to challenge the preeminence of fossil-fuel sources of electricity generation for redevelopment.

Avoiding the topic of climate change entirely, the group's messaging focused on air pollution instead. Noting that deregulated markets had contributed to ambient air pollution, they allied with a group of agitated Texas mayors who were struggling for their municipalities to meet air quality standards. The mayors were upset with the Texas Utility Commission's proposals to build new coal-fired power facilities upwind from their towns threatening their compliance with ambient air quality requirements and the attached federal funding. To avoid air pollution as an unintended consequence of deregulation, the group wrote a rider provision to SB7 requiring 3% of all Texas electricity to be generated from renewable sources: an RPS. A Green Credit was created to incentivized any kind of renewable electricity generation within the state with costs levelized with the dominant baseload generation sources[1].

Texas Senate Bill 7 (1999) contained the RPS and was ultimately passed, because the RPS satisfied economic profit imaginations of West Texas communities and Dallas energy entrepreneurs. It addressed the political system concerns of many Texas mayors who were near noncompliance

[1] The green credit incentivizes the purchase of renewable energy and is given legal priority on the power lines. If natural gas generated electricity sets market price on the Texas power grid at 15 cents per kW/hr, then renewable-generated kW/hrs would be sold at the same rate.

with federal ambient air standards (Clear Air Act) and anxious about the consequences of a deregulated market threatening their municipalities' federal funding if they are out of compliance. SB7 satisfied advocacy groups reliant upon a science function system that evidences the need to mitigate a changing climate. This policy eventually evolved into Texas utility-wide programming and funding that linked the construction of transmission lines and other market changes within ERCOT (cf. Fischlein et al. 2010) which further anchored Texas' wind energy industry. However, the purpose here is to show how system resonance enabled the initial actions that changed the trajectory of the energy development in Texas. Within this story, are lessons for sustainability science research to identify key points within a system for interventions.

Brokering resonance: identifying "The sweet spot"

Addressing climate change requires the synergy of more than a single social function system and no single policy can guarantee its mitigation. Wind energy flourishes in Texas due to resonance across several social functions.

For the economic system, wind energy in Texas has become profitable (Galbraith and Price 2013). In the mid-2000s, the price of natural gas rose, which set the marginal market price of electricity in the Texas deregulated wholesale market. Wind-generated electricity sold at natural gas prices coupled with the state RPS's Green Credit subsidy and the Federal Production Tax Credit made wind energy a financially certain and profitable investment.

> "Well, to put it just more bluntly, businesses can make money building wind farms now. And that's why T. Boone, you know he wants to build wind farms 'cause he can make money doing it. And for this stuff to be really successful that's what has to happen. Texas is sort of the sweet spot…because it has the great wind, we can do big monster projects, enormous projects. And you're competing against high priced fuel. So all the factors have just come together beautifully here" (TX 12).

Within the cultural system, the technology appeals to Texans in several ways. First, the appeal of the wind turbine lies in its simplicity.

> "Everything you do, from a coal plant to a nuclear plant to natural gas plant to a wind farm is to get you to the point where the generators are turning. In the case of wind, it's wind blowing and blades turning. For coal it is extraction, combustion, a mixture of water and all that stuff. The steam generated. For nuclear it's a huge process as you know. All to get to the same point of generators turning. And so the appeal of wind power is the simplicity of it" (TX 13).

Fig. 2 McCamey, Texas welcome sign. Photo Credit: McCamey Chamber of Commerce, http://www.mccameychamber.com/

Second, 100-m-tall turbines fit the landscape of Texas.

> "Texans embrace big stuff. You know if you were to go into New England or California, they had this extreme NIMBY [Not In My Backyard] syndrome. They wouldn't want 300-foot-tall turbines in their backyard. But out in west Texas, absolutely. Bring them on! You know I'd love to get some revenue off of those suckers. And so it's just a different mentality that we have here" (TX 12).

Third, wind electricity generation fit the identity of West Texans as producers for the rest of the state. Much of West Texas has a legacy of food and energy production.

> "I really think there's a cultural difference between people that have embraced this idea that they're a producer for other people. And so through these farming communities, energy producing communities, they accept this stuff because that's what they do. That's their job: to produce stuff for other people" (TX 12).

Texans are early adopters of wind technology, because it fits their lifestyle. They embrace turbines, because turbines leave ranching and farming on large ranches undisturbed and wind turbines reinforce Texan identities as producers. Texans accepted the technology, because it is straightforward and familiar. Wind turbines have been used in West Texas for pumping water, oil, and generating electrical power before rural electrification brought power to homes (Galbraith and Price 2013).

That the technology fits Texas culture is evidenced throughout West Texas communities. The image of the windmill is accepted as part of the horizon of Texas skyline. It has achieved an iconic status, such as the iconic Texas longhorn, the cowboy, the oil well, the whitetail buck, and like the other landscape features, as seen in the

West Texas town of McCamey's welcome sign (Fig. 2) and on license plates. Wind energy has fit the values and identities of Texans, and it has made West Texas a story of economic rebirth (Galbraith and Price 2013).

Looming threats

In addition to aligning the RPS to political function system interests of influential West Texas legislators, policy interveners leveraged the absence of federal climate-change policy as a looming threat to the economic certainty of coal and natural gas electricity in a future carbon-constrained economy. In a deregulated market, the mere threat of federal climate policy changes the decision making calculus of GHG emitting industries considering new generation plants. Thus, climate change is more threatening as a political reality that signals economic risk than a climatological reality.

> "I come from a finance and law background. And so I don't consider myself to be qualified to reach an informed conclusion with respect to whether or not global warming is due to manmade activities… However, I think it's a political reality. And so in today's world, whether you are a business leader or a political leader, you'd better have a climate-change strategy or one will be [forced] upon you" (TX 19).
> "The oil interests by and large have been the last to talk about climate change as a real interest because they're threatened by the carbon control or potential carbon control…I mean people are talking about it. Obama's been elected, you know. "Oh my god, what's he gonna do about climate change? You know, it is sort of in a fear mongering type of way we're talking about climate change" (TX18).

The mere possibility of a comprehensive federal climate-change policy that would reconfigure how financial risk is assessed and thus how capital flows to fossil-fuel sources of electricity production is a prominent specter within the Texas policy landscape (Cox 2010). The effect of this unknown political and legal system change on the economic function system continues to shape the renewable energy industry in Texas.

The political and legal function systems continue to support the wind industry through policy increasing the RPS goals (SB20 in 2005). While SB7 gave wind energy in Texas the initial push by enabling ERCOT to integrate wind into the Texas grid and electricity market, the industry was further advanced by an economic push from natural gas pricing and uncertainty surrounding looming federal policy followed by a USD 4.93 billion investment in transmission lines to connect West Texas wind energy to Texas' population centers—the Competitive Renewable Energy Zone (CREZ)—which was paid for by the entire system (Fischlein et al. 2010; Stephens et al. 2015). Coupling this momentum with the additional investments in transmission infrastructure, the industry will continue to grow. With the high penetration of renewables, Texas has transformed from an "oil state" to an "energy state".

Discussion

Policy formation and institutional change are enormously complex with an assemblage of institutions and individual actors; the purpose here is not an attempt to explain causal means of how legislation (the RPS) are brought into law or implemented. There are a number of widely used explanatory frameworks of policy change and implementation (cf. Kingdon 1995; Lorenzoni and Benson 2014; Sandfort and Moulton 2015). Our objective is to showcase how various social function systems may be brought into alignment by events, policy trends, policy interveners, business and policy entrepreneurs, technological advances, and other factors to achieve social system change that may otherwise seem unlikely. At the macro social function system scale offered by Luhmann's system theory, resonance provides a theoretically cogent account of the anatomy of a sustainable solution.

Our conversations with policy insiders contextualize how a policy was structured for its best fit into existing political, economic, legal, and cultural function systems within the specific problem setting: illustrating how resonance can be triggered. The story of Texas' wind industry demonstrates how Luhmann's theory of system resonance functions in the real world. The science of global climate change resonated with Texas environmental NGO (eNGO) leadership as well as with educators enough to enter into the social function of education. A college student told his father about his concern for the changing climate and the environment. It resonated with his father's long-term cultural knowledge of his hometown, his attachment to place, and his personal economic interests. Partnering with eNGO leaders and the business community, policy interveners framed this environmental disturbance as an economic opportunity written as a rider to a popular senate bill appealing to targeted legislators' economic, cultural, legal (air pollution), and political interests. These interested interveners strategically aligned function system values to broker resonance. Through the legal structure of the RPS, the economic function system was assured that renewable energy investors could deliver renewably-generated electricity to the market. As Texans are fond of saying, "the wires don't care what kind of electricity they carry". With revenues from the new technology benefiting economically distressed communities, social and political groups welcomed wind turbines as a part of Texas' physical, economic, social, legal, cultural, and political landscapes. The technology was embraced by Texans and simultaneously reinforced identities as producers who do things "big". Many of the interviewees stated that "Texas got the law right" found that "sweet spot". The sweet spot is the space of convergence, where multiple function systems' value logics are satisfied by a series of "solutions". A characteristic of resonance is a self-rearrangement of function systems that leads to rapid exponential reproduction (growth). Resonance is a novel alignment of existing value logics (e.g., renewable electricity is profitable) that has overcome the inertia of the status quo (e.g., fossil fuel only electricity) into a reconfiguration that gathers its own momentum (e.g., jobs, new businesses, ERCOT market changes, and CREZ) surpassing the original triggering seed (e.g., NGOs targeting a law to combat climate change) to be driven and sustained by multiple function systems. While the RPS policy sparked resonance across the function systems, this policy no longer drives development and implementation. It is the simultaneous satisfaction of multiple function systems' values that animates renewable energy growth in Texas. It is likely that industry successes in Texas have amplified the resonance capacity in other places via economies of scale driving down costs of wind energy technology, the development of technical expertise, and public acceptance of wind energy among conservative audiences.

Although whole-system resonance is rare—individual function systems are overly self-absorbed and prefer not to change—occasionally ecological information can force a break in business-as-usual social functioning. Environmental disturbances—such as climate change and DDT—can successfully trigger resonance across different social systems into policy/action when strategically positioned to align with the operational particularities of societies' social function systems in a specific place (Cox 2010; Hall et al. 2012b; Peterson et al. 2010). Just as strategic communication interveners can create signals that alter the decision calculus within social function systems at relevant sites of power with some consequence (cf. Cox 2010; Hall et al. 2013) and policy interveners can spark resonance, transformational sustainability science researchers too can play a role in the system description, analyses, stakeholder engagement, and experimental interventions needed to initiate and administer resonance (Wiek et al. 2011).

Luhmann's social systems theory offers a vantage for communicating, conceptualizing, and identifying pathways towards sustainable solutions. As a framework, it can be used to assess a problem setting and evaluate potential solutions across different functional systems. The general characteristics of function system descriptions enable a pliability for application to diverse problem settings. Researchers and practitioners could use the pursuit of resonance as a framework for systematically considering social players and functions to be engaged for transformational research. For example, examining renewable technology deployment with the social function systems in mind may improve long-term planning (Stephens et al. 2008, 2009; Fischlein et al. 2010; Hall and Lazarus 2015). Resonance may be used to critique well-meaning concepts that benefit conservation but are too limited in their over eagerness to satisfy a single function system at the expense of its own long-term viability; like ecosystems services (Peterson et al. 2010). Lasting social change must simultaneously satisfy several social functions and achieve some degree of resonance to self-perpetuate. Furthermore, where sustainability science has been critiqued as offering mostly case studies from developing countries (Ehrenfeld and Hoffman 2013) rather than addressing the source cultures of developed nations, Luhmann's social theory is scaled for thinking about sustainability problems in both the global north and south.

Discussion of overcoming the sustainability gap cannot overemphasize the importance of attending to the human dimensions. Human behaviors are the basis of social–ecological problems and these behaviors must be the target of solutions. Sustainable solutions are contingent upon the problem setting; they leverage the history of community desires and identities and understand, respect, and enhance ecological functioning (Peterson 1997; Honadle 1999; Fischer 2000; Norton 2005; Clark et al. 2016). This calls for robust social and cultural theoretical frameworks that address multiple scales to shock groups out of social-functioning-as-usual and into new ways of thinking (Adorno and Bernstein 2001). Brokering resonance operates as a strategic disruption that re-orients behaviors towards sustainability, yet behavioral changes retain compatibility with core social function system values (cf. Varner et al. 1996). Solutions are dependent upon and driven by committed, often—long-term—residents and embedded actors (researchers) familiar with the social, economic, political, and cultural context. Through an in-depth understanding of social and cultural functioning, transformational researchers can identify ways of satisfying multiple value logics of social function systems simultaneously. This involves the creative coordination of resources, capacities, and information into new ways of seeing the system which are useful for designing strategic interventions in the setting. Whatever collective, coordinated, and re-organized actions are enacted, they must resonate across various sectors while taking root in the language, values, and identities of the people (Campbell 1974; Hall et al. 2013, 2016; Norton and Thompson 2014) if they are to be lasting transitions.

Conclusion

The nature of sustainability problems defies a singular lens. Addressing complex social–ecological problems requires coordinating efforts and synchronizing ambitions of multiple sectors of society (science-policy gap and the sustainability gap). Problems in translating scientific knowledge into actions (policy, behaviors, and solutions) are relational problems between science and society (Fisher 2000; Sarewitz 2004; Cash et al. 2006; van Kerkoff and Lebel 2006; Pielke 2007; Spruijt et al. 2014). Such relational problems require a requisitely sophisticated means for conceptualizing the system. Luhmann's theory of system resonance accounts for how self-organizing social function systems within societies can hear and then respond (reorganize) to environmental risks—effectively offering an explanation of how human and natural systems are coupled.

Luhmann's social function system theory and the phenomena of resonance offer a means of considering and communicating these relations. Resonance offers a grammar for designing solutions-oriented research as the strategic coordination of capacities, resources, and information to address multiple related problems in a manner consistent with existing site-specific value logics. From Luhmann, sustainable solutions must bring together many aspects of the social realm to align the organizing logics of multiple sectors (e.g., science, society, economy, religion, culture, law, politics, education, and others) to simultaneously fit with the existing logics (norms, values, grammars, etc) of social systems. The case above demonstrates that isolating climate change—as politicians do as a separate and discrete problem—is not enough to achieve sustainable solutions that are adaptable to social changes over time. Novel configurations that resonate with the existing values of many social function systems are necessary for lasting change. Such configurations endure, because they address one of "the greatest sustainability challenges" noted by Charles Redman of moving "forward in a fast changing world and yet hold[ing] onto the traditional beliefs and values that give society meaning and help people keep an even keel" (Guyot 2011: 12).

Luhmann's notion of resonance offers important guidance to sustainability scientists and activists who seek to alter society's response to the growing threats posed by climate change. Singling out the problems of climate change as discrete to the environment and disconnected to other functional systems continues to be ineffective. A more holistic approach that integrates a plethora of sustainability-related initiatives, and focuses on actions (i.e., implementation of solutions) that explicitly and iteratively connect climate mitigation with cultural norms, social justice, intergenerational justice, human rights, economic transitions, and efforts to minimize degradation of human and environment systems, is a better route for transformative sustainable solutions. Perhaps, this quest for integration aimed at achieving resonance will become a central theme of the emerging field of sustainability science. By focusing on developing resonance across social systems, sustainability science researchers are more likely to help bridge the sustainability gap.

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