From Sustainability to Transformation: Dynamics and diversity in reflexive governance of vulnerability

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Abstract

This paper slightly amends a concluding chapter in the above book on '*vulnerability in technological cultures*'. It offers a personal view of key governance implications of this fruitful concept. Picking up earlier arguments, technological vulnerability is seen in a dual fashion – both in terms of the vulnerability of particular technological trajectories to subversion by powerful incumbent interests, as well as the vulnerability of societies and ecologies to the effects of technology. Either way (in common with other kinds of vulnerability), those interests which tend to be most adversely affected by these dynamics, are those that are already most disadvantaged.

The argument begins by pointing out that governance institutions and discourses around Sustainability hold particular significance for this challenge. By contrast with prevailing (simply emergent) notions of progress, Sustainability constitutes political space and traction for more assertively publicly-deliberated normative frames. These in turn help enable greater social agency concerning the appropriate orientations for innovation pathways that pay greater respect to *qualities* of ecological integrity, social equity and human wellbeing.

Beyond these normative dimensions, however, Sustainability also focuses attention on diverse possible *dynamics* of vulnerability. Distinguishing between styles of agency variously conceived as *controlling* or *responsive*, and temporal patterns perceivable as episodic *shock* or cumulative *stress*, four distinct dynamic properties are resolved (*stability, durability, resilience* and *robustness*). Each holds contrasting practical implications for governance institutions and instruments. But all address vulnerabilities in a fashion that assumes a normative interest in *maintaining* a given trajectory. The contrasting face of vulnerability also requires attention to an alternative normative aim: that of *disrupting* a given trajectory. Here, the same four dimensions of agency and temporality highlight four corresponding dynamics of disruption (*transduction, transition, transilience* and *transformation*).

If governance is to escape from the powerful conditioning effects of incumbent interests, this framework may offer a basis for greater critical reflexivity over contrasting normativities and dynamics of vulnerability. So, the paper ends with a brief exploration of the implications for three interlinked aspects of diversity – involving the '*opening up*' of ways in which technological trajectories are: epistemically *understood*; normatively *appreciated*; and ontologically *performed* in practice. It is argued that taking the dual faces of technological vulnerability seriously, requires attending more symmetrically to these essential conditions for more distributed and relational forms of social *reflexivity*. Only by this means, is it possible to escape not only the diverse ways in which incumbent concentrations of power *close down* technological trajectories themselves, but also the plural ways in which the general dynamics of technological vulnerability can even be imagined.

1. From "Broadening Out" Appraisal to "Opening Up" Commitments

This chapter turns our attention from knowledge to action. In so doing, it will go beyond a focus on epistemic aspects, concerning *indeterminacies* in social *understandings* and normativities around the natures and origins of technological vulnerabilities (Jasanoff, 2005). Consideration will shift instead to more ontological dimensions, to do with *intractabilities* associated with *enactments* of the socio-technical choices themselves (Feenberg, 2002; Rip, 2009). This engagement with the challenges of vulnerability in technological culture is constituted not so much by characteristics in our ways of *knowing*, but by features in associated (social, technical, and "natural") ways of *being* (Leach, Scoones, & Wynne, 2005).

In this way, a focus on intractabilities brings to the fore questions of *action* and *temporality*. After all, it is only by reference to (variously framed) human needs, normativities, intentions and interventions (associated with " action"), that we may apprehend whether or not various possible states of being are experienced as "vulnerabilities" in the first place. Likewise, it is only through contemplating dynamics over time (expressed as "temporality") that we experience the actual tractability or recalcitrance of such vulnerabilities in the face of actions to forestall or mitigate them. It is thus primarily in terms of these dual dancing parameters of action and temporality that unfolding socio-technical "progress" may be apprehended in any given instance either as "marching forward" (Smith & Marx, 1994) or "biting back" (Tenner, 1996) in relation to vulnerability – or as some contested ambiguity between the two.

In previous work I have focused on the ways in which power interacts with knowledge and normativity in the *social appraisal* of socio-technical choice (Stirling, 2008a). Organizational, cultural, political, and economic forces structure our understandings of technology change, so as to further compound the vulnerabilities (Jasanoff, 2004). These dynamics come to a head with a series of intractable problems in conventional methods and institutions of "risk regulation" (Jasanoff, 1990; Wynne, 1995). As a response to these challenges, crucial lessons arise in the application of the precautionary principle. Among other things, these urge a "broadening out" of the "tools," practices, and institutions through which society comes to understand the contending pathways that are open for socio-technical choice – as well as their respective implications and consequences (Stirling, 2008b). Only in this way can we extend attention to alternative trajectories reflecting wider and deeper notions of "benefit" and "harm." Only by more fully informing our understandings of socio-technological potentialities may we enable commitments to pathways that truly reduce technological vulnerabilities (Leach, Scoones, & Stirling, 2010b).

The following discussion will engage with the implications of these issues for technology governance in a series of steps. In the next section, I will review the dominant ways of framing vulnerabilities in terms of contrasting notions of sustainability. This enables us to make explicit the crucial, but often concealed, role of contested normativities. Section 3 will then explore the dual parameters of agency and temporality introduced above. Acknowledging the importance of contending framings, this will discern systematic contrasts between temporalities of vulnerability expressed (or represented) as "shock" or "stress" and styles of action undertaken (or conceived) as "control" or "response." These parameters are shown systematically to decompose sustainability into a series of quite distinct subordinate dynamic (ideal-typical) properties.

Section 4 will then discuss the implications of this more nuanced picture of vulnerability in technological culture, for the practical design of governance interventions. A diversity of

strategic possibilities will be highlighted, with different interventions tending to counter contrasting aspects of vulnerability. Governance strategies will be reviewed involving distinct kinds of infrastructure qualities, institutional practices and modes of innovation that are relevant in contrasting contexts. However, it will also become clear that a number of other governance strategies display more general applicability to different aspects of vulnerability – including especially various forms of socio-technical diversity.

Finally, in Section 5, attention will turn back to the question of framing. I will show how political and economic power can operate such as to "close down" the appreciation of appropriate governance interventions, and restrict attention disproportionately to the "control" of "shock" to maintain "business as usual." Marginal and critical perspectives also tend to be sidelined by presumptions that the necessary focus must always be on maintaining, rather than disrupting, incumbent socio-technical trajectories. It is by giving equal weight to governance interventions aimed at transformation as well as sustainability that we may best hope to address the full depth of the challenges presented by vulnerability in technological cultures.

2. Sustainability, Normativity, and Vulnerability

Perhaps the most prominent and longstanding articulation of notions of action and temporality in contemporary governance of vulnerability in technological cultures lies in the potent and pervasive policy concept of "Sustainability" (Adger & Jordan, 2009). Here we see the clearest and most influential expression of contemporary normativities of "technological progress" (Stirling, 2009). More particularly, it is under the auspices of "Sustainability" that the principle of "precaution" has become a central theme in current controversies over the *understanding* of vulnerability, as well as over *actions* to be taken in response to it. Attention to "Sustainability," therefore, allows us to move from essentially cognitive predicaments – such as uncertainty, ambiguity, ignorance, indeterminacy and incommensurability – to the challenges of intentionality and agency bearing on the vulnerabilities themselves and their associated possible responses. Alongside this shift from understanding to action, ustainability also requires attention to the temporalities of these interventions and this requires the enacting of properties like stability, durability, resilience, robustness, transduction, transition, and transformation. These are the issues to be discussed in this chapter.

Despite the essential interlinkages, concepts of "sustainability" have an ambiguous and multifaceted relationship with vulnerability – and in particular with the human dimensions of this (Leach, Scoones, & Stirling, 2010a). The advent of this notion in high-level governance discourse was important and distinctive precisely in that it promised an enhanced profile, rigor and priority in policymaking for the vulnerabilities of the least powerful and most marginal people. For the Brundtland Commission, Sustainability was famously summarized as "*meeting the needs of the present, without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development, 1987). Although the progressive novelty of this principle is often characterized as resting on the attention to "future generations," the emphatic requirement that the needs of the present also be met is even more immediately radical. For more than two decades, "Sustainability" has thus been the principal high-level global policy discourse enjoining the reversal of persistent maldistributions of privilege, appropriation, and exclusion affecting a large proportion of the world's population.

Another aspect of Sustainability discourses in relation to vulnerability is that the precise normative implications of sustainability remain disparate, ambiguous, and contested (Murcott, 1997). The essential thrust of this concept in formal governance rests on three broad sets of normative aims – each addressing different qualities of vulnerability. The first concerns human wellbeing – including health, education, and community as well as economic development (United Nations General Assembly, 2000). The second relates to social equity – across diverse kinds of groupings among both present and future generations (United Nations Division for Sustainable Development, 2002). The third refers to environmental integrity – in terms of various forms of ambient pollution, ecological integrity, and resource availability (Matravers, Moldan, & Billharz, 1998). Precise interpretations of the implications of the broad normative aims – as well as definitions for associated indicators, criteria and targets – are emphasized in global sustainability discourses to be a matter for inclusive public deliberation in the settings in question (Final Declaration of the UN Conference on Environment and Development, 1992). This political-processual dimension of Sustainability is crucial, because it requires participation from – and accountability to – the most vulnerable people themselves (Dobson, 1996). Yet, despite the clarity and profile of these formal provisions, impacts of "Sustainability" policies on vulnerability continue to unfold in ways that are more modest, expedient, and even counterproductive (Meadowcroft, 1999).

One reason for these connections between Sustainability and vulnerability being sometimes counterproductive is the pressure for an instrumental usage of this kind of high-level policy rhetoric in order to justify commitments that are rather differently-motivated (Wynne, 2002). With sustainability, there is a particular expediency in that the broad colloquial meaning of the common verb "to sustain" (in English as in other languages) refers generally to the maintaining over indefinite periods of *any* unspecified features, qualities, or functions. This provides a linguistic license for nonspecific terminologies of sustainability in ways that are inattentive, ignorant, or actually potentially undermining of the highly specific and carefully-deliberated values of Sustainability itself (Walker & Shove, 2007). In this chapter I will therefore use the capitalized term "Sustainability" to refer to the (albeit themselves variously-defined) Brundtland triad of publicly-deliberated qualities: human wellbeing, social equity, and environmental integrity (Stirling, 2009b).

The received global policy concept of Sustainability thus has an explicitly normative thrust. The quality levels to be sustained in the face of vulnerability are not fixed but aspirational and to be improved. For instance, the 1995 World Summit on Social Development defined "Sustainable Development" not in terms of the Brundtland Commission's "meeting of needs" but as "the framework for our efforts to achieve a higher quality of life for all people" (The World Summit for Social Development, 2009, p. 1). In other words, it is an additional normative implication of Sustainability that what is being sustained is not some static level in publicly-deliberated qualities of human wellbeing, social equity, and environmental integrity. Instead, it is about a continuous progressive *trajectory of improvement*, as seen from a "future subjunctive" vantage point focused on the situations of the most vulnerable people (Robinson, 2003). It is with this fundamental clarification of the normativity that we can turn to consider some of the more detailed – and crucial but neglected – implications of Sustainability for vulnerability.

3. Agency and Temporality in Sustainable Reduction of Vulnerability

So far, attention in this discussion has focused on normative qualities implicated in Sustainability and vulnerability, whose progressive improvement it is intended to be sustained. We have seen how both qualities and improvements may variously be framed in quite radically different ways. Indeed, this is why the specific reconciliations of ambiguities in any given context are a matter for inclusive deliberation and public accountability (O'Riordan, 2001). However, it is not only the specific normative orderings that are subject to divergent framings. The physical systems themselves are often subject to such different framings too (Leach, et al., 2010a).

The implications of contrasting framings of Sustainability in socio-technical systems extend far beyond different "scales" of assessment, or "system" definitions, or "levels" or "units" of analysis (Jasanoff, 2005). Divergent frames typically concern much more fundamental ontological commitments that underlie and crosscut all these kinds of analytical constructs (Ison, Maiteny, & Carr, 1997). Even where there is agreement over specific normative characterizations of human wellbeing, social equity, or environmental integrity, contrasting perspectives and engagements may each yield radically divergent consequences for the design, implementation, and interpretation of policy interventions aimed at reducing vulnerability (Schön & Rein, 1994). Divergent framings not only exist of "actors," "technologies," or "vulnerabilities," but also of the "trajectories" of these assemblages. In this sense, the "context" for any given Sustainable response to vulnerability includes not only a multiplicity of "objects," but also a diversity of "subjects" – and the mutually co-conditioning relations between the two (see Figure 1).

Some key concepts: a "context" of divergently-framed "vulnerabilities," "technologies," and "actors" for a given socio-technical "trajectory."
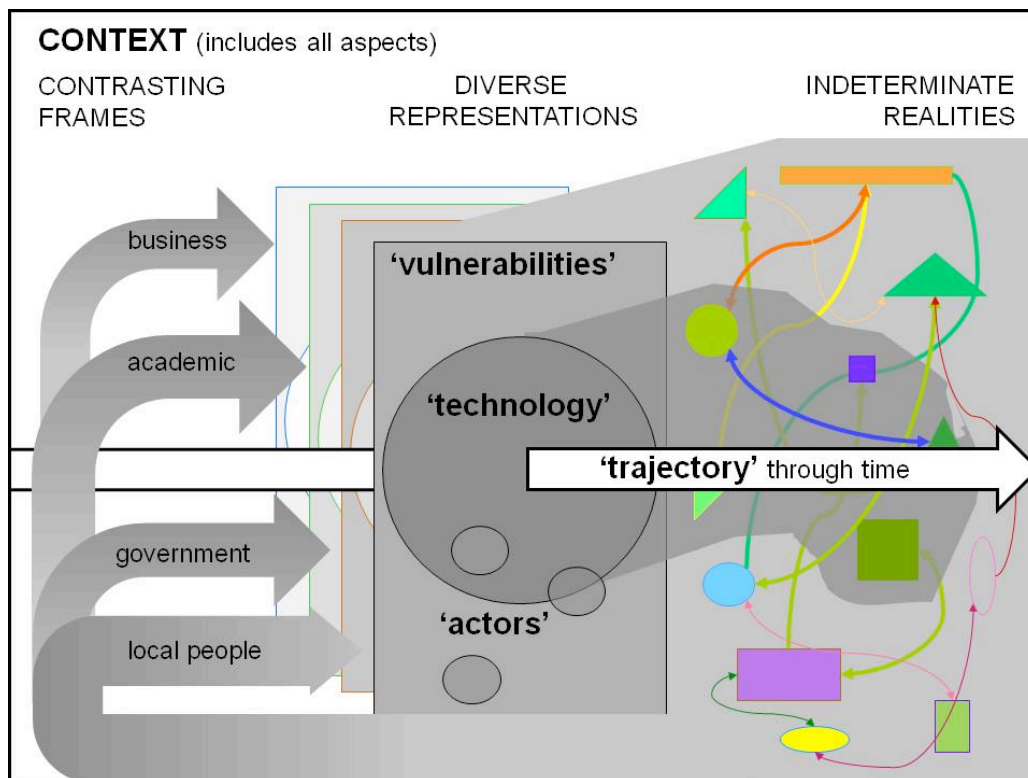
It is against this background of divergent framings of vulnerability and Sustainability that we may best appreciate the imperative to "open up" contrasting implications under different perspectives and contexts (Stirling, 2008a). Although the parameters of "action" and "temporality," with which this chapter began, represent only two dimensions among the many that constitute the diversity of possible frames, they do provide a basis for examining, through two fairly pervasive "principal components," the effect of more diverse engagements with both vulnerability and Sustainability alike. Rather than asserting some fundamental ontological status for these two parameters of action and temporaility, the aim of this chapter is to introduce a *heuristic* and *analytic* apparatus for discerning – and "opening up" – more nuanced and robust approaches to governance of socio-technical vulnerabilities in general (Leach, et al., 2010a).

In these terms, then, temporality refers to contrasting dynamics of disturbance that constitute the vulnerabilities against which Sustainability is a counter. In short, the issue is whether threats are seen as *short-term episodic shocks* or *long-term secular stresses* (Stirling, 2007b). Of course, like any heuristic contrast, this distinction is relative, with a spectrum of possible gradations. Any precise positioning depends on the circumstances and the scales under scrutiny – as well as the subjective context of the framing perspective in question (see "context" in Figure 1). Yet, I will argue here that there is considerable value in this basic heuristic distinction between different *framings* of temporalities. Typical examples of sources of vulnerability represented as "shocks" include spikes in global commodity prices, epidemic outbreaks of zoonotic disease, and severe episodes of flooding. Examples of vulnerabilities routinely represented as "stresses" include long-run trends in global markets, demographic shifts, and changes in climate.

If vulnerabilities are seen to involve short-term transitory perturbations (**shocks**) forcing disruptions in otherwise stable socio-technical trajectories associated with steadily improving qualities, then the central task (and reference point) is the *maintenance* of the trajectories in question. For instance, investment in storage for food surplus is a strategy to control poor farmer's vulnerability to drought. Likewise, the building of coastal defenses is a strategy to control coastal vulnerability to storm surge events. If, on the other hand, the same vulnerabilities are viewed as driven by enduring long-term pressures, reflecting underlying shifts in conditions (**stresses**), then the focus is on how to sustain the qualities in question under what might be fundamentally changing circumstances. Attention is thus on adapting prior established trajectories in what may be quite profound ways. For example, if the episodic droughts to which farmers are vulnerable are instead interpreted to reflect long-run climate change, investment in new agronomic practices is likely to yield a more sustainable counter to vulnerability than would provision for storage in existing food systems. Similarly, coastal defenses that are effective against episodic storm surges will nonetheless be overwhelmed by progressive secular sea-level rise – against which a more sustainable long-term response might be managed retreat.

Under any given normative framework, then, Sustainability measures that address vulnerabilities framed in terms of shocks will be relatively *conservative* in their implications for relevant institutions, practices, and infrastructures (Meadowcroft, 1999). This is because the aim is simply that of sustaining vulnerable qualities through intermittent disruptions. When the temporality of disturbance is interpreted as stress, however, sustainable reductions in vulnerability can (even under the same normative framework) present much more *radical* political challenges. Instead of achieving improving quality under essentially continuous conditions, the objective is to achieve this under fundamentally changing conditions. These dynamics are generalized in the stylized picture in Figure 2a below.

An additional key dimension to governance for Sustainability (no matter how viewed) concerns the style of action envisaged. In short: is the aim to reduce vulnerability by *controlling* change, or by *responding* to it (Stirling, 2007b)? Once more, the complexities of intentionality, agency, causality and intractability in the real world lie along a spectrum between these dichotomous poles. And this continuum is itself typically constituted in very different ways, depending on context and perspective. Again however, the purpose here is not one of ontological taxonomy but heuristic analysis: to highlight an important distinction that is otherwise frequently elided. Alongside shock and stress shown in Figure 2a, Figure 2b represents schematically the essential difference between styles of action aiming at control or response. As with the earlier contrast between shock and stress, this distinction between controlling and responsive action holds important practical implications for governance strategies aimed at sustainable reductions in vulnerability.

A style of action oriented towards *control* rests on a conviction that the drivers of the changes in question (whether shocks or stresses) are in principle *tractable* to deliberate intervention. This requires a number of conditions to be fulfilled. First, there must be confidence in the quality of the understandings of the relevant causal relationships. For instance, the etiological structures underlying the relevant vulnerabilities must be seen as *determinate* and *predictable*. This resonates strongly with risk-based epistemologies. Representations of knowledge may thus typically embody the restrictive assumptions discussed there. A second condition for tractability is that drivers must not only be generally *susceptible* to action, but must offer specific *moments*, *modes*, and *locii* for manageable interventions, which are identifiable and achievable with available instruments, time, and resources. Third, there must be confidence that the consequences of such interventions will

be restricted to those that are desired and predicted. Any qualifications on these conditions for tractability will undermine claims that shocks or stresses are "subject to control" (see Figure 2).

FIGURE 2a:
Contrasting temporalities in addressing technological vulnerabilities
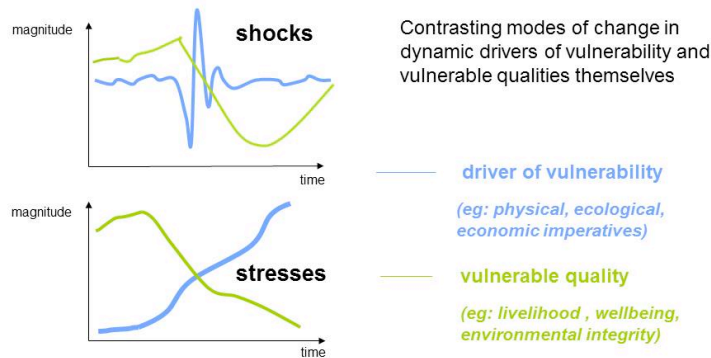
FIGURE 2b:
Contrasting temporalities and actions in addressing technological vulnerabilities
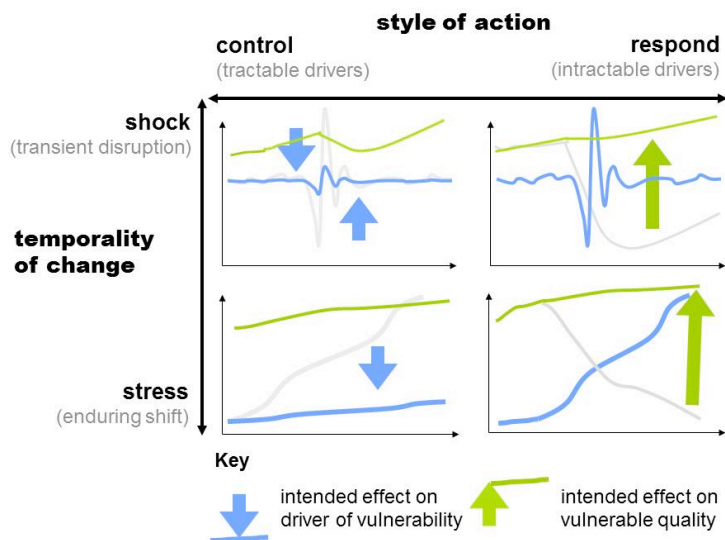
Rather than aiming to control drivers of change, a "*responsive*" style of action aims directly to address the emergent consequences. Even under the most bullish of perspectives, this is the residual course of action where the phenomena in question are held to be intractable – perhaps because the drivers themselves are seen to be inherently indeterminate or unpredictable, or because the necessary time, resources, or loci for interventions are seen to be non-existent. Either way, responsive action may still be anticipatory. But with relevant drivers seen as intractable, action is simply more circumscribed in its ambitions to engage with underlying causes. The distinctive characteristics of responsive action lie rather in the more qualified, conditional, iterative, reflexive style – and greater humility – than is typically associated with governance interventions oriented towards control (Stirling, 2006).

This interplay between temporality of change and styles of action constitutes four quite distinct dynamic properties (Stirling, 2007b: Figure 4). As with the heuristic distinction

between four contrasting framings of incertitude, these properties should not be understood as mutually exclusive or collectively complete in relation to real-world instances. Instead, they are Weberian "ideal types" that emerge from any discrimination between parameters of temporality and action. Their utility will rest on their salience to the practical governance of technological vulnerabilities. In particular, the value of the present framework lies in opening a door to more plural and differentiated understandings of the contexts for intended action. This will be discussed in the next section. For the moment, what is striking about the four dynamic properties that emerge, is that they correspond closely to semantic distinctions that are long established in existing dictionary definitions for widely used colloquial terms (Simpson & Weiner, 1989): "stability," "durability," "resilience." and "robustness" (see Figure 3).

FIGURE 3:
Four necessary but individually insufficient dynamic properties of sustainability
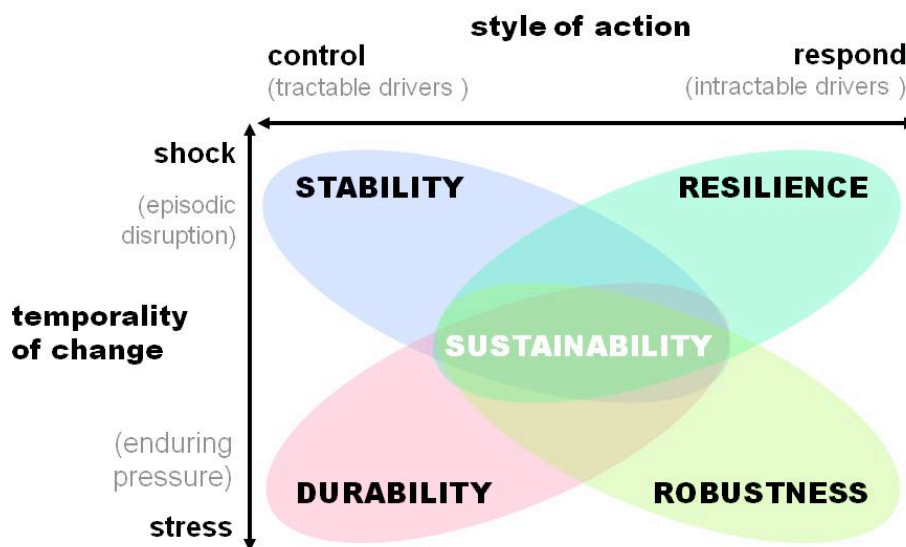
The value of this scheme is that it highlights a mutually-consistent set of collectively-necessary but individually-insufficient dynamic properties that are implicated in what it means to sustain anything (Stirling, 2007b). The distinctions are therefore highly relevant to the governance of Sustainability in general and to contrasting aspects of technological vulnerability: that of social possibilities to the consequences of socio-technical choice and of potentially foregone socio-technical trajectories to the effects of social closure. Taken together, these four ideal-typical dynamic properties apply to any continuous trajectories (of whatever kind) that are subject to agency in the face of change (Dawson, Rounsevell, Kluvánková-Oravská, Chobotová, & Stirling, 2010). *Stability* is where transitory shocks are tractable to control. *Durability* is where secular stresses are tractable to control. *Resilience* is where transitory shocks are accommodated by response. *Robustness* is where secular stresses are accommodated by response.

As with nonspecific usage of the term "sustainability" discussed above, it follows that the normative implications of these dynamic properties intrinsically depend on evaluations of the trajectories to which they refer. Where trajectories are defined in terms of technological

or institutional configurations that are seen as problematic, then (as with the general sustaining of these trajectories themselves) specific properties of stability, durability, resilience, or robustness will, of course, be judged to be negative. Only if the trajectory in question is regarded as good, does it follow that these associated dynamic properties will be positive. Crucially, this also means that these properties are only self-evidently positive if the focal trajectories are defined not in terms of means to ends (e.g.: technological or institutional structures), but the normative ends themselves. In our terms, then, this applies only where trajectories are defined in terms of improvements for the most vulnerable groups in publicly-deliberated qualities of human wellbeing, social equity, and environment integrity. It is here that properties of stability, durability, resilience, and robustness can be seen to constitute collectively-necessary but individually-insufficient conditions for Sustainability in the face of vulnerability.

4. Vulnerability and Strategic Diversity

So far, the implications for governance of vulnerability of sustainability and resilience have been discussed in quite general terms. The heuristic framework developed here holds practical strategic significance too (Leach, et al., 2010a; Stirling, 2007b). Strategies aiming at stability focus on controlling what are held to be tractable drivers of shocks to any given system. Strategies aiming at durability focus on controlling tractable drivers of stress. Strategies aiming at resilience focus on responding to intractable drivers of shock (represented as external to the trajectory). Strategies aiming at robustness focus on responding to intractable drivers of stress. I shall elaborate these strategies by discussing a few examples.

Recall the case of spikes in costs of global commodities (like primary fuels, agricultural inputs or industrial feedstocks) mentioned earlier as "shocks" that can affect vulnerable groups like subsistence farmers or other economically marginal households. Here, control-oriented governance interventions may aim directly to achieve stability through regulating the relevant prices in the markets, thus directly manipulating the cause of the shock as experienced by those who are vulnerable. In cases where governance entertains greater ambitions to agency, efforts at controlling for stability may take the form of trade sanctions against the responsible producers, thus forcing a lowering of the prices. Either way, such control actions contrast with response-oriented strategies aiming at resilience, which take the prices to be intractable to control and instead focus on capacities or measures that ameliorate the effects on the vulnerable groups. Resilience-oriented interventions undertaken in anticipation of global price spikes might include the fostering of *flexible* supply chains (Costello, 2004) or *redundant* alternative production capabilities or resources and capacities (Farrell, Zerriffi, & Dowlatabadi, 2004) to *substitute* for the commodities in question. The aim is to absorb the impact of global price spikes affecting particular resources, without actually controlling the market prices themselves. If it turns out that the price spikes are intermittent and of short duration, then control-oriented strategies for stability may appear most effective. However, if the disruptions are more frequent and long-lasting, then resilience-oriented strategies will likely be judged preferable. A failure to distinguish parameters such as whether action is in the style of control or response may therefore obscure an important practical consideration in the governance of vulnerabilities to shock.

Another example mentioned above was the vulnerabilities of poor farmers to shocks from drought. These might be addressed by investing in facilities enabling storage of surplus from earlier, more favorable, years. However, drought might alternatively be interpreted as an incipient indication of stress. Episodic droughts might be feared to presage a shift in local climate towards a much drier regime. In this event, control strategies would aim at durability rather than stability – focusing on influencing the drivers of stress rather than shock. One such control-style, durability-oriented intervention might be to secure shifts in the trajectories of farmers' livelihoods, effecting a long-term "agronomic transition" away from drought-sensitive crops and towards more drought-tolerant species or practices. Similar contrasts may be found between environmental quality measures aimed at controlling episodic pollution events and public health interventions dealing with transitory epidemic outbreaks. Either will differ strongly from regulatory measures to control long-term cumulative rises in pollution or the trends towards chronic endemic disease. In all these examples, attention focuses on control-style strategies. But – like the contrast between stability and resilience – there is a clear practical distinction between controlling strategies oriented towards stability against shock and those aiming at durability under stress.

So too is the distinction between resilience and robustness of practical importance for governance strategies. For instance, low-income riverside settlements are vulnerable to short-term shocks from storm-surge flooding. This may be addressed by control-style, stability-oriented strategies focusing on construction of engineered river defenses. Alternatively (as with global market prices and drought), such shocks might be interpreted as beyond feasible attempts at control. This suggests response-style strategies aiming at resilience: like provision of sanctuaries and retrofitting of flood-resistant features in critical infrastructure facilities like schools, hospitals, and major sources of employment. These do not seek to control the driving causes of flooding, but instead focus on *minimizing* loss of life and structural damage, maximizing continued *functionality* and *accelerating recovery* – making it easier, cheaper, and quicker to respond to flooding when it occurs. However, as in the case of drought risks to farmers from climate change, responses to flood vulnerability may also be seen in terms of long-run secular trends, rather than transitory shocks. Being equally intractable to control, this will again be a cue for response-style strategies, but this time with an entirely different character. Intractable drivers of stress require strategies for robustness: in this case taking the form of land-use and livelihood changes, involving managed retreat from the most vulnerable flood plains. Here, the implications contrast strongly with resilience strategies, which would have involved greater investment in the structures on these same flood plains from which robustness strategies require withdrawal. Again, there emerge strong practical implications for governance action in the face of vulnerability.

Figure 4 takes this discussion a step further by highlighting in a more systematic way further circumstances where the present distinctions between stability, durability, resilience, and robustness may be crucially important to strategies for reducing vulnerabilities in technological cultures. With respect to technological infrastructures, for instance, there are potentially important distinctions to be made between the ways in which strategies for reliability may provide for stability, while strategies for flexibility may offer a better basis for resilience (Collingridge, 1980). Electricity systems provide a concrete example. Here, strategies for increased reliability may aim to stabilize the system by increased maintenance, over-engineering transmission and distribution equipment, or over-provision of generating capacity. Resilience, by contrast, may be better achieved through flexibility, by broadening staff training, ensuring redundancy between facilities dependent on different fuels, or building "dual-firing" capabilities that can accommodate multiple fuels as inputs. Yet these

infrastructure strategies for both reliability and flexibility may each also contrast with (and trade-off against) strategies for persistence as a means to foster durability. This may be achieved, for example, by more expensive facility siting (like underground burial) or the use of more impermeable, renitent, or non-corroding infrastructure materials. Finally, strategies for reliability, flexibility, and persistence alike may each contrast in important ways with strategies for adaptiveness. Instead of consolidating existing infrastructures in these various ways, adaptive strategies like diversification promote robustness under stress through enabling open-ended but fundamental reconfigurings of the infrastructures themselves (Jones, 1992).

The point is not to assert some reified ontological differentiation between reliable infrastructures, flexible infrastructures, persistent infrastructures, and adaptive infrastructures. Nor is it the purpose to insist that these distinctions will always be practically salient. The intention is rather to highlight the *potential* significance of these kinds of contrasting strategies for promoting contrasting dynamic properties. Without a framework for at least making these distinctions, we cannot be sure that we are not simply behaving like the proverbial under-equipped carpenter armed only with a hammer for whom every problem is a nail.

FIGURE 4:
Contrasting strategies for stability, durability, resilience and robustness
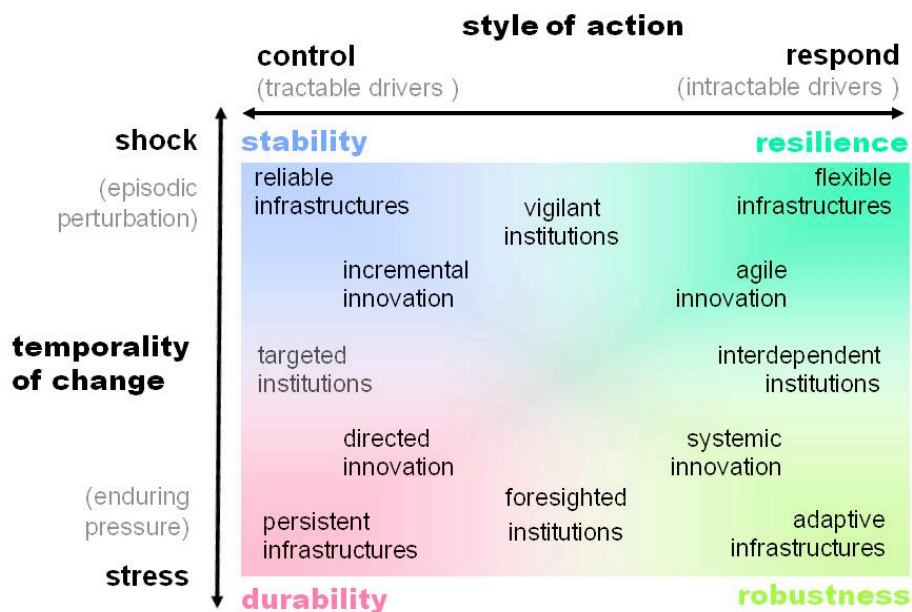
In this same heuristic spirit, Figure 6 also suggests important differences between strategies for institutional design (Ostrom, 2005). Where the aim is simply to control some specific identified form of shock or stress, strategies may aim at tightening institutional remits, concentrating capacities, or buffering complex interdependencies. Yet these very strategies for *isolated* or *autonomous* institutions may perform more poorly where the aim is to achieve sensitive responses to complex intractable disturbances that are beyond the reach of control (Jessop, 1998). Under these latter circumstances, more *open remits*, *distributed capabilities*, and *interdependent* relationships are probably more effective (Kooiman, 2003). Likewise – irrespective of whether the ambition is to control or respond – there may be important contrasts between institutional capacities and processes that foster *vigilance* in the face of short-term transitory shocks or *foresight* in the face of long-term secular stress.

The third example illustrated in Figure 4 concerns innovation strategies. This refers to well-established contrasts between "incremental," "directed," "agile," and "systemic" innovation, which may resonate in interesting ways with each of the dynamic properties distinguished here. The iterative adjustments of *incremental innovation* allow controlled forms of stability, especially under successive transitory parameters of change (Freeman & Perez, 1988). *Directed innovation*, on the other hand, helps to control for durability in the face of some specific identified stress (Stirling, Geels, Scrase, Smith, & Van Zwanenberg, 2009). *Agile innovation* may be undertaken where the broad orientation of trajectories is clear, but without seeking to control in advance all sources of possible perturbation (Oza & Abrahamsson, 2009). Finally, *systemic innovation* seems more appropriate where it is the orientation of the trajectories themselves that must be changed in the face of some secular stress, thus requiring innovation at an architectural level (Andersen & Drejer, 2008).

Unlike those discussed thus far, there are certain governance strategies where the available literature suggests more widely applicable potential. Candidate examples of these kinds of more "multivalent" strategy might include enhancing equity, engaging stakeholders, promoting learning, catalyzing reflexivity, and fostering diversity. *Enhanced equity* in particular is obviously both an outcome of reduced vulnerability, but also a means to reduce the vulnerabilities in the first place. This is so, irrespective of whether greater equity is achieved through controlling or responsive interventions, or in the face of threats seen to be manifest as shock or stress. Likewise, deliberative and *participatory engagement* are argued to offer broad benefits in the governance of vulnerability, independently of the dynamics of the envisaged disturbance or the style of intended action. Related qualities of *learning* and *reflexivity* all also appear in the literature as being similarly potent in relation to a range of dynamic properties (Argyris & Schön, 1978; Sabatier & Jenkins-Smith, 1993; Voss, Bauknecht, & Kemp, 2006).

Perhaps no single strategy is more multivalent than *diversification* (Stirling, 2007a). Here, a particularly extensive literature documents many ways in which deliberate nurturing of technological, institutional and behavioral diversity can help foster all the dynamic properties of sustainability discussed here (Page, 2007). First, socio-technical diversity permits higher degrees of fidelity and context-sensitivity to contingent cultural and bio-physical heterogeneities. This can help to reduce exposure of vulnerable communities to the consequences of globally-homogenized technological cultures. Second, socio-technical diversity hedges against intractable forms of incertitude. Avoiding "all eggs in one basket" helps both ameliorate vulnerability to surprise and the associated consequences when surprise occurs (Brooks, 1986; Rosenberg, 1996). Third, diversity mitigates socio-technical "lock-in." By resisting the "crowding out" of configurations favored by marginal groups, this can help to combat both kinds of vulnerability identified at the start of this chapter. Fourth, socio-technical diversity is increasingly understood to foster innovation (Kauffman, 1995; Rosenberg, 1982). Whether the innovation is envisaged as incremental, agile, directed, or systemic – each can benefit from diversities of interacting institutions, applications, practices, and technologies (Grabher & Stark, 1997; Landau, Taylor, & Wright, 1996). Fifth, socio-technical diversity provides a way to address otherwise irreconcilable political challenges in social choice, by accommodating the plural values and interests associated with advocacy of contending technological pathways (Stirling, 2010b). In these ways, consideration of diversity further illustrates how some governance strategies may be more multivalent than others in their promotion of different dynamic properties. This is of crucial potential importance for the governance of vulnerability, but is more easily missed, where the properties themselves remain undifferentiated.

5. Power and the Framing of Vulnerabilities in Technological Cultures

This chapter began by emphasizing the importance of explicit attention to the dynamics of framing in thinking about vulnerability and its relevance for designing governance strategies. This discussion of stability, durability, resilience, and robustness has so far proceeded exclusively by reference to properties of socio-technical vulnerabilities themselves, rather than to the contexts and perspectives under which they are viewed. It now remains to attend to the social processes through which these properties are framed (Leach, et al., 2010a).

This brings us to the pervasive effects of political, economic, and institutional power. I have shown elsewhere how these various processes serve to help "close down" social commitments around technological pathways favored by incumbent interests (Stirling, 2008a). Part of this phenomenon is the way that power also operates in the institutions and practices of knowledge appraisal to condition not only the concrete actualities of the choices, but even the form of our knowledges concerning the underlying potentialities themselves. Figure 5 shows how an array of institutional cultures and practices exert formative pressures on our understandings of knowledge itself (Stirling, 2010a). It is this feature of wider institutional environments, which provides the conditions under which reductive-aggregative methods flourish (Stirling and Scoones, 2009). In effect, political, economic, and institutional power tend consistently to move appreciations of vulnerability away from the more open, humble, sensitive, and reflexive characterizations found on the right and lower sides of the diagram and move these up into the relatively closed, narrow, hubristic, and inflexible representations found in the upper left-hand quadrant.

FIGURE 5:
Institutional Pressures from Power to "Close Down" Knowledge of Vulnerabilities
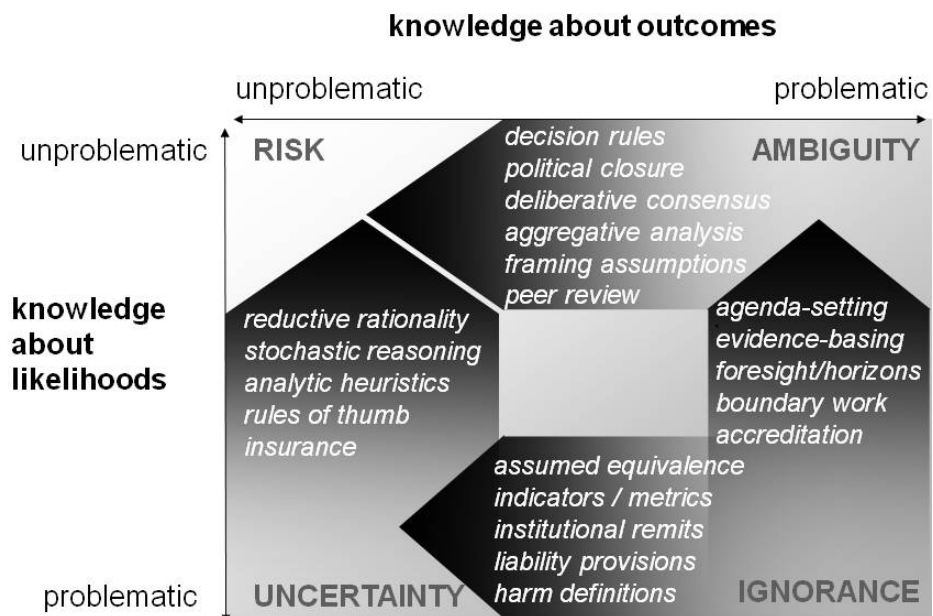
These formative effects of power in "closing down" the framings of incomplete knowledge in social appraisal can help us to explore how these epistemic implications resonate with the more ontological aspects of governance intervention. Do there exist similar dynamics in the framing of the properties and strategies addressed here concerning alternative temporalities of vulnerability and styles of intervention?

Even on the basis of the discussion thus far, the answer seems quite immediately to be "yes." The "social ecological resilience" literature, for instance, documents – and criticizes – how existing governance interventions aimed at mitigating technological and other vulnerabilities tend consistently to highlight control-based strategies over response-based strategies (Berkes, Colding, & Folke, 2003; Folke et al., 2004; Folke, Hahn, Olsson, & Norberg, 2005; Gunderson & Holling, 2001; Holling, 1978).Yet, this same resilience literature itself tends to elide contrasting normativities, structure and function, shock and stress (Smith and Stirling, 2010). In each respect, the effect of closure under dominant framings is to favor incumbent interests. Presuming that the normativities of resilience are self-evident would assert hegemonic values at the expense of less visible interests of more marginal groups. Conflating structure with function would identify means with ends, again taking for granted a commitment to incumbent structures. Finally, by masking differences between episodic shock and enduring stress, undifferentiated notions of "resilience" would highlight transitory perturbations that favor "business as usual" by incumbents, thus occluding the more potentially radical challenges of robustness under long-term secular change.

Taken together, this presents a basis for a more general and systematic hypothesis concerning the framing of dynamic properties. Figure 6 builds on longstanding insights in a wider literature (Jasanoff, 1990, 2005; Schön, 1973; Scott, 1998) to indicate (in this case through shading) a hypothetical tendency for incumbent governance actors to direct their attention most enthusiastically in the lighter area extending from the property of stability. The argument is illustrated by examples from UK government framings of vulnerabilities in energy security policy (Joint Energy Security of Supply Working Group (JESS), 2004). The smaller font in Figure 6 identifies the strategies that are cited most prominently in recent official UK policy. The most frequently-cited strategies are aimed at securing the property of stability: where challenges are framed expediently in terms of controlling transitory disturbance to maintain the *status quo ante*. That there are fewer mentions of resilience-oriented strategies suggests that the associated relinquishing of aspirations to control is intrinsically less attractive under these incumbent perspectives.

Likewise, there seems at least a *prima facie* case that strategies aiming at durability also tend in general to be relatively less favored by incumbents than those oriented towards stability. This suggests similarly unfavorable views of the associated necessity to contemplate the radically changed conditions that flow from recognition of stress. Only if the particular altered conditions in question are somehow resonant with prevailing interests will durability prove appealing under dominant perspectives. Finally, it is striking from their forming the least frequent of all kinds of strategies that UK energy security policy interventions oriented towards robustness are evidently least prominent of all in the attention of incumbent actors concerned with strategic responses to vulnerability in this major infrastructure.

What of the framings by more radical or less powerful interests? Vulnerabilities fall disproportionately on the most marginal communities. They are a consequence both of collateral harm caused by dominant trajectories, as well as the ways in which "lock in" to these "crowds out" the subaltern pathways favored by disadvantaged interests. Accordingly, there is a need for special effort in the governance of vulnerability to direct particular attention to the perspectives and circumstances of the most vulnerable groups, to counter the routine emphasis afforded to incumbents. It is arguably the persistent exclusion or sidelining of marginal and critical perspectives on vulnerability that constitute one of the most crucially neglected aspects of the actual technological vulnerabilities themselves.

FIGURE 6:
*Incumbent Bias to Stability Strategies– example from UK energy security policy*

Of course, as indicated in Figure 1, there will typically exist a rich variety of possible framing perspectives on any instance of vulnerability. The views of marginal and vulnerable groups may themselves be expected to be correspondingly plural. But, amidst this diversity, the single most important consideration with respect to governance interventions focusing on any particular socio-technical trajectory will concern whether the motivating purpose is to maintain or disrupt that trajectory. Here, it is necessary to repeat the distinction between structure and function. It may be difficult to imagine why any serious political perspective would wish deliberately to disrupt – as an end in itself – the provision of fundamental functional qualities (like the "Brundtland triad" of human wellbeing, social equity, and environmental integrity). Yet it is much less difficult to recognize situations where there are legitimate interests in disrupting particular incumbent sociotechnical trajectories (like that of global fossil fuel infrastructures or weapons of mass destruction). It is at this structural level that a focus on the neglected dimension of intentional disruption becomes most salient.

Here, a key axis for analysis encompassing a diversity of framings centers on normativity concerning the incumbent trajectory. Where the focus is on maintaining an incumbent trajectory (in whatever way) the perspective in question may be referred to broadly as (normatively) "inside" the incumbent discourse. Where the intention (for whatever reason) is one of disrupting this incumbent trajectory (in order to enable some alternative pathway), the perspective in question is correspondingly (normatively) "outside" the incumbent discourse. It is in this light that we can appreciate how the pattern of emphasis in governance interventions summarized in Figure 6 applies specifically to framings of the dynamics of vulnerability conditioned by broadly "inside" perspectives. The discussion of the social ecological perspective that followed Figure 6 considered the slightly different kind of framing evident in these somewhat more critical academic perspectives, which are distinguished by their readiness to countenance the limits to control. But, this still implies a broadly positive "inside" view of the basic features of the trajectories in question – one highlighting the potential for response rather than control.

What is different about Figure 7 is that it adds to this picture a complementary – but even more neglected – picture. It is based on the same heuristic framework used repeatedly here to articulate "temporality of vulnerability" and "style of action." But this time, we find included in a systematic and symmetrical way, not only the dynamic properties of interest under positive (incumbent, "inside") views of trajectories, but also the corresponding dynamic properties that are of interest under negative (subaltern, "outside") views of these same trajectories. This allows recognition of a further suite of dynamic properties that, in several ways, represents the complements of stability, resilience, durability, and robustness discussed thus far. Instead of describing the different ways in which socio-technical trajectories may be *maintained* by control or response in the face of shock or stress, these properties describe a range of corresponding ways in which such trajectories are susceptible to reorientation through *disruption*. I will refer to these as transduction, transition, transilience, and transformation.

FIGURE 7:
Contrasting framings of target properties in governance action against vulnerability
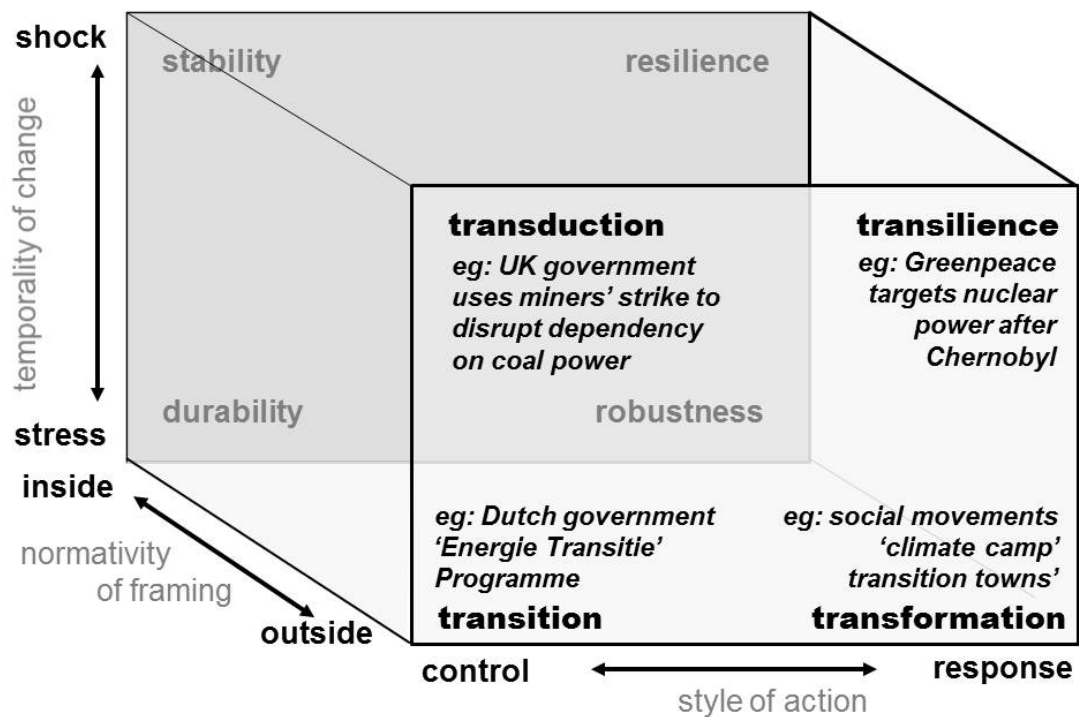
Of course, this further dimension in the possible dynamics of socio-technical trajectories is already widely recognized, not least in the social ecology literature. Folke et al. point out, for instance, that "[a] resilient social-ecological system may make use of crisis as an opportunity to transform into a more desired state" (Folke, et al., 2005, p. 441). The role of transition and transformation are often pointed to elsewhere in this field (Evans, 2008; L. Gunderson, 1999; Holling, 2004; Ludwig, 2001; Olsson, Folke, & Hahn, 2004). But, especially when articulating (ecological) functions and (socio-technical structures), this kind of juxtaposition of "resilience" and "transformation" can compound the ambiguity inherent in the fundamental conflation of structure and function in this literature reviewed earlier (Smith &

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Stirling, 2010). If so much is lumped together under the single dynamic property of resilience, it can become unclear exactly what is being maintained and what is being disrupted. It is in order to address this kind of potential ambiguity – and the resulting confusions or strategic manipulations in governance – that it may be seen as necessary and helpful to adopt the three-dimensional representation shown in Figure 7. As with the two-dimensional grids employed thus far, the purpose is not to assert some even more elaborate ontology. The point is: only by envisaging these dynamics of framing in three interlinked dimensions of normativity, temporality, and agency it is possible properly to encapsulate the multivalent relationships between different kinds of dynamic properties and associated governance interventions.

In these terms, the dynamic property referred to in the foreground of Figure 7 as "*transduction*," is one where control-oriented interventions seek to exploit conditions of short-term episodic shock, such as to disrupt the socio-technical trajectory in question. In this sense, transduction is an antonym of stability in that stability describes the propensity to maintain trajectories in the face of shock, while transduction relates to the role of shock in facilitating disruption to these same trajectories. Here we see again the dual face of vulnerability, in that pursuit of stability is driven by concerns over vulnerabilities *experienced by* a trajectory while harnessing of transduction may arise from concerns over vulnerabilities *caused by* that same trajectory.

An example of a situation in which control-style actions were aimed at disrupting an existing sociotechnical trajectory in very specific and targeted ways, can be seen in the interventions of the UK government against coal power in the 1980s. The over-riding purpose then – as key protagonists acknowledged later – was to exploit the shock of a specific instance of industrial action by miners to affect a more far-reaching disruption to the trajectory of the electricity supply industry as a whole. In particular, a key aim was to achieve a shift to a significantly different (and to the Government of the day, less vulnerable) socio-technical trajectory based more on nuclear power. This example underscores the point made above: that it is not only marginal perspectives that may favor disruption. In this case, the UK Government was a very powerful political actor armed with many options for control-style strategies. But it was nonetheless in some important sense "outside" the particular incumbent framing associated with the trajectory of the coal-based electricity supply industry itself – and wished to see this disrupted.

Likewise, there is a dynamic property that is of corresponding importance to resilience under vulnerability, but which arises only where outside perspectives are taken into account. This is referred to in Figure 7 as "*transilience*." Although rare, this word is actually an existing English noun that has been employed for hundreds of years in a way that fits quite well this suggested usage (Simpson & Weiner, 1989). In these terms, the dynamic property of transilience is a susceptibility of a trajectory to be disrupted by responsive actions in the face of shock. For consistency, an example here may also be drawn from the energy sector. As the author knows from personal experience, the major international environmental NGO, Greenpeace, maintained its campaigning focus against the global civil nuclear industry during the 1970s and 1980s on the specific target of irradiated fuel reprocessing (and associated waste management). Greenpeace did so because these parts of the nuclear infrastructure were analyzed to be most vulnerable to actions intending to disrupt the nuclear trajectory as a whole. The more specific part of the industry constituted by nuclear power was then held to be less vulnerable to radical political action. However, the Chernobyl accident in April 1986 presented a shock to exactly this part of the industry. For the first time, there arose the opportunity for responsive actions by outside actors to

effect disruption to the core trajectory of the contested industry. This particular form of vulnerability on the part of a global energy infrastructure illustrates a counterpoint to resilience, for which it is interesting that there already exists the (neglected) term "transilience."

The dynamics of "transition" as defined in Figure 7 also correspond very closely to the conventional usage of this term. Indeed, there is an entire literature on "technological transitions," in which the term is used in senses that predominantly centre around exactly this meaning (Stirling, 2011). A transition occurs where some specific long-term stress forms a basis for control-style strategies aimed at disrupting an incumbent trajectory towards a very specific reorientation. Particular resonance can be found here in the "transition management" literature, which focuses disproportionately on control-oriented management instruments, rather than broader and more "political" governance interventions (including "response" strategies) (Genus & Coles, 2008; Shove & Walker, 2007; Smith & Stirling, 2007). Arguably the best example of this in the energy sector is the Netherlands Government's current "Energie Transitie" program – aiming at a national transition to a low carbon infrastructure (Rotmans et al, 2001; Smith, et al., 2005). In this case, the stress that these control-style government actions are intending to exploit (as well as address) is the material and discursive political pressures presented by prospects of global climate change. It is crucial to the "control" dimension here, that both the stress itself and the "low carbon" endpoint are quite specific. Although paying attention to distributed networked and participatory processes, this "transition" program is well known for its emphasis on central coordination and managerial interventions by government agencies, rather than distributed market processes or more diffuse forms of political engagement driven by civil society (Seyfang & Smith, 2007; Smith, 2007).

"*Transformation*," the final new dynamic property defined in Figure 7, contrasts in exactly these ways with transition. While a transition implies some specific controllable endpoint, transformation is inherently more open-ended (Stirling, 2011). Transformation also contrasts with transilience, as defined above, in that it implies change in the face of some enduring shift, rather than episodic shock. In this sense, then, the property of transformation may be defined as occurring where responsive interventions harness contingent stress to help catalyze radical reconfigurations, whose exact nature is not subject to control. To take a final example from the technological politics of energy systems, it may be no coincidence that this property comes to the fore when contemplating the roles of more marginal political actors than those considered thus far: social movements arising in grassroots civil society. These are not in a position, like government, to seek to exercise control. But their circumstances also contrast with those of major international NGOs like Greenpeace in that their more diffuse and marginalized positions provide less of a basis for responding opportunistically in timely and targeted ways to some particular contingent shock. Civil society organizations like "climate camp" and "transition towns" therefore seek more exclusively to lever change around discourse concerning long-term, large-scale secular stresses (such as "peak oil" and climate change). The potentially transformative consequences are also more distributed, diffuse, and diversely oriented than a single "transition," opening up a more indeterminate array of possible alternative trajectories.

It is in these ways that the symmetrical representation of "outside" as well as "inside" framings in Figure 7 highlights the importance of a range of more diverse and nuanced dynamics than are conventionally made explicit in the governance of vulnerability. The context, style and orientation of governance interventions can all be seen to vary quite radically, depending on the prevailing circumstances. The conventionally undifferentiated

dynamics of sustainability can – under "inside" framings – be resolved into distinct arenas for governance action in pursuit of stability, durability, resilience, and robustness (as in Figure 3). These each have counterparts under "outside" framings in transduction, transition, transilience, and transformation. These latter conditions for disruption constitute necessary but individually insufficient conditions for the neglected counterpart of sustainability: changeability. If we wish to attend fairly to the full range of implications of vulnerabilities in a technological culture, we need to address both changeability and sustainability when debating and designing governance interventions.

Figure 7 thus also shows that vulnerability is more plural, complex, nuanced, and recursive than is often acknowledged. While the present heuristic framework may offer quite concrete ways to prompt questions and test hypotheses, the main value may lie in helping to catalyze a generally more open and reflexive appreciation of the governance challenges posed by these multivalent dimensions of vulnerabilities in technological cultures.

Conclusions: Towards Reflexive Governance of Technological Vulnerability

This chapter highlighted the importance of distinguishing contrasting dynamics of vulnerability (associated with shock and stress) and styles of intervention (aiming at control or response). Exploring these key dimensions revealed a heuristic array of four contrasting dynamic properties that are individually necessary and collectively sufficient for the sustaining of anything (stability, durability, resilience, and robustness).

In short, different dynamic properties require contrasting governance strategies. There may be important trade-offs, which are neglected in conventional, less differentiated, approaches to sustainability and resilience. In particular, it emerges that marginal interests are again quite systematically sidelined because conventional approaches are preoccupied with properties under which incumbent trajectories are *maintained*. To remedy this bias, attention extended in this chapter to a corresponding series of further dynamic properties associated with the *disruption* of incumbent trajectories. By focusing on the nature and implications of these neglected properties of changeability (transduction, transilience, transition, and transformation), I argued that we can achieve a more complete appreciation both of the technological vulnerabilities themselves – and of the associated options for governance intervention. I argued that such a fuller picture is especially important, when there is a desire to counter the constraining framing effects of power and focus attention instead on the vulnerabilities of the least powerful.

Figure 8 summarizes these converging strands of argument by relating them to a series of complementary elements in the "reflexive governance" of vulnerability (Voss, et al., 2006). Featuring particular strongly here, however, is one further specific theme developed in this present chapter: the importance of epistemic, normative, and ontological diversity (Stirling, 2007). Starting in the lower left hand side of Figure 8, we see how social appraisal can achieve more broader-based and precautionary understandings of – and learning about – vulnerabilities in a technological culture. This emerges from (and engages with) a wider array of issues, options, uncertainties, benefits scenarios, and perspectives. These in turn interact with the normative plurality conditioned by divergent contexts, perspectives, and interests to "open up" greater transparency and accountability in wider policy discourses concerning the potentialities in technology choice.

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FIGURE 8
Towards more progressive and reflexive governance of vulnerability

FIGURE 8
Towards more progressive and reflexive governance of vulnerability
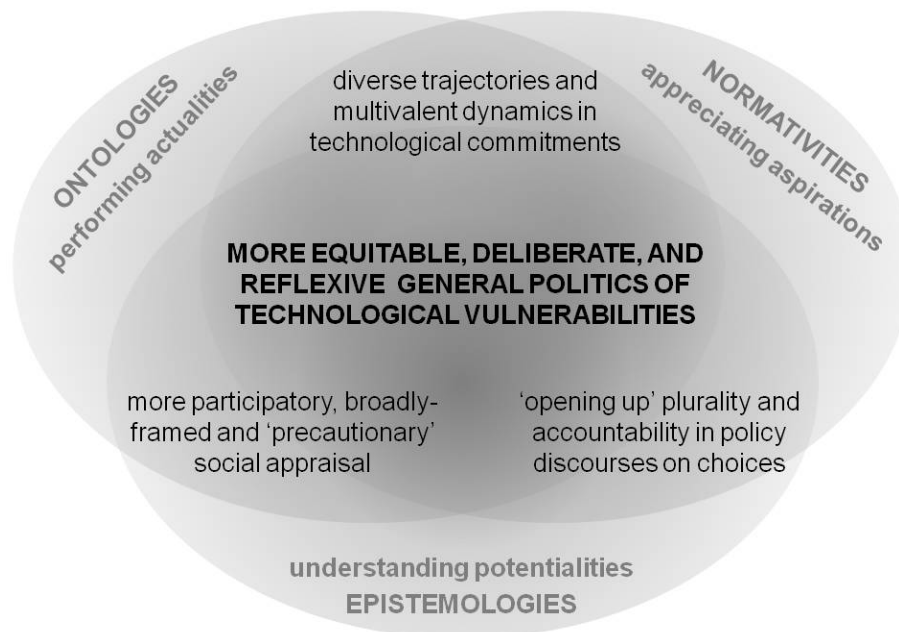
Of course, in the real world, institutional commitments need to be made and decisions must be justified. This is indicated at the top of Figure 8. But here again, it is possible to mitigate globalized technological monocultures by pursuing instead a more deliberate diversity of contending technological trajectories. Part of this lies in actualizing more multivalent dynamics in these trajectories – realizing the full range of properties that have been defined in this chapter. So may the natures of our technological commitments help nurture more plural ontologies, returning us to the left hand side of Figure 8. It is in this way that the recursive interactions between epistemic, normative, and ontological pluralism may help to maintain more reflexive governance of vulnerability (Stirling, 2011). Rather than depending on cognitive ideological or procedural exhortations of individual actors, this institutional notion of reflexivity arises in distributed unstructured political space. By helping to reduce pressures for closure in every domain, this enhanced pluralism may also afford greater political scope for those marginal voices and interests otherwise suppressed by more structured institutions and discourse. It is in these ways that the dynamics of diversity, reflexivity, and more equitable governance of vulnerability may be seen to be profoundly interlinked.

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