

Section B: Transition Strategies

Governing Sustainable Industrial Transformation

Under Different Transition Contexts

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Introduction

In recent years, the analytical lens in innovation and environment studies has tended to pull back from firm-level processes of cleaner technology innovation. Studies have refocused on wider, linked processes that green the *systems* of social and technological practice by which we satisfy our needs for housing, mobility, food, communications, leisure, and so forth. These ‘socio-technical regimes’ have become the focal unit of analysis, and the challenge is to transform them into more sustainable configurations (Berkhout, 2002).

The new focus on regimes places earlier analytical concerns in a broader context, recognising that firms and technologies are embedded within wider social systems. Some of the reasons cleaner technology is not diffusing rapidly through firms, for example, relate to the overarching structure of markets, patterns of final consumer demand, institutional and regulatory systems and inadequate infrastructures for change. On issues such as these, firms have limited room for unilateral manoeuvre. However, the new focus is motivated by an additional assumption, that only radical changes at the regime level can deliver sustainable development (Rotmans and Kemp, 2001). The new focus seeks to understand and guide ‘systems innovation’ in order to facilitate not only greener firms, but more sustainable practices from all participants in any given socio-technical regime.

In transforming the industrial sustainability agenda in this way, the governance challenge becomes more ambitious and more demanding. We have argued elsewhere that approaches to sustainable systems innovation have hitherto been somewhat restricted. Despite the breadth of the concept, there is a tendency to treat regime transformation as a monolithic process, independent of important differences in *context* (Berkhout, Smith and Stirling, 2003). We also argue that existing approaches tend to be too descriptive and structural, leaving room for greater analysis of *agency* as a means to more informed, deliberate and effective processes of regime transformation. In short, if we are to engage both analytically and normatively with the complexities of governing sustainable systems innovation, there is a need for more explicit and detailed conceptual tools. In this chapter we propose as a heuristic, a systematic framework for understanding different transition contexts and associated governance implications. Our specific objectives are threefold:

1. To encourage greater attention to agency in our understandings of transitions in socio-technical regimes.
2. To distinguish more clearly between different elements in the context for regime transition: the *articulation* of selection pressures, and the *adaptive capacity* available to facilitate regime transformation.
3. Recognition of these different contextual elements is likely to affect both descriptive understandings and normative recommendations. We aim to explore some of the resulting practical implications for the governance of sustainable technology strategies.

With this particular interest in governance, we address the crucial question of agency by introducing the notion of regime *membership*. This recognises that technological regimes are not unitary entities, but involve the active co-ordination of lower order agency on the part of institutions, networks and actors as regime 'members' in their own right (see also Jacobsson and Johnson, 2001). This given, our model of regime transformation is then a function of three factors. First, the degree to which the selection pressures bearing upon a regime are *articulated* towards a particular direction of transformation on the part of regime members. We argue that without this articulation of selection pressures the conditions for systems innovation do not exist. Second, the degree to which the resources required for effective regime transformation (factor endowments, capabilities, positioning) are available either within or beyond the members of the incumbent regime. Third, the degree to which the response to these pressures is *co-ordinated* in a coherent fashion across regime members. It is these latter two elements (the ability to co-ordinate responses and the availability of resources), that we identify as the '*adaptive capacity*' available for regime transition (Berkhout, Smith and Stirling, 2003). In the end, the particular form and direction of regime transformation – and the associated modes of governance– will depend on the 'transition context': a function of the availability of resources and how they are coordinated.

The analytical framework presented here is preliminary, speculative and heuristic. The chapter is organised around each of the objectives above. The next section discusses the regime concept at greater length and, in particular, the networks of actors, institutions and processes by which regimes are reproduced. After this we discuss the origins of change for socio-technical regimes. We suggest that transformation processes can be organised according to whether they contribute to the articulation of selection pressures (exerting a demand for change), or whether they contribute to the availability of adaptive capacity (resourcing a co-ordinated response to selection pressures). Governance of regime transitions involves modifying the balance of selection pressures and adaptive capacities. It follows from this that different patterns of transformation can take place, depending upon the prevailing transition context. We introduce a simple typology to help map such transition contexts and guide the analysis of governance for regime transition.

Mapping Socio-Technical Regimes – an Agency-Based Approach

Socio-technical regimes are relatively stable configurations of institutions, techniques and artefacts – as well as rules, practices and networks – that determine the 'normal' development and use of technology in order to fulfil socially-determined functions. Regimes thus embody strongly held convictions and interests concerning particular technological practices and the best ways in which these might be improved. Modern agriculture, for example, has evolved along a trajectory in which increased factor productivity has been the goal, measured in terms similar to industrial productivity. This regime has consequently focused on mechanisation, specialisation

and increased inputs of energy and chemicals that have boosted massively the agricultural output per unit of labour. In the meantime, an alternative conceptualisation of agricultural goals has struggled to gain limited acceptance. Organic farming was originally pushed by a small group of dissenting voices around the same time that the principles of modern agriculture were being embedded in government policy in the industrialised world in the 1930s and 1940s (Conford, 2001). Organic farming focuses on output per unit land area, usually favouring mixed farms, and is concerned with nurturing soil fertility through the relatively closed cycling of materials. It is only now beginning to reach the status of a substantial niche socio-technical activity (in the sense that there is a robust network of actors and institutions supporting the organic approach to agriculture).

But this sketch points up some of the problems with employing a concept as broad as the technological regime. It begs a number of questions: Where do we draw the boundaries of the regime? What constitutes the membership of a regime? In what sense can regimes be seen as competing? Is the source of selection pressures on regimes other competing regimes, or do they stem from broader societal factors? In this section we take as a starting point the behaviour of agents that constitute regimes.

Socio-technical regimes and their empirical application

In the established literature, the term 'regime' is used as a short-hand for a series of complex, nested real world phenomena, embodying natural and artificial physical elements, as well as social, economic, cultural and cognitive attributes. Regimes exist across different empirical scales, and can be seen as constituting the social and economic functions which they serve.¹ At a relatively high level of aggregation, the electricity generating regime is widely dominated by social rules and practices relating to centralised, large scale (usually thermal) power technology and high voltage alternating current grid infrastructures. Consumption patterns and supportive institutional arrangements are built around and reinforce this pattern of energy utilisation. This has been the 'normal' way of producing electricity in industrialised countries for at least eight decades. However, at the lower level of aggregation of individual power technologies, the electricity generating regime as a whole spans a variety of nested subordinate regimes, such as that based on the coal-fired steam turbine, the nuclear fuel cycle, large scale hydroelectricity or gas-fired combined cycle turbine systems. At this level, even within the emerging niche for renewable generated electricity, we may identify an incipient regime dominated by 3-bladed, horizontal axis megawatt-scale wind turbine operating in grid connected clusters and supported through public policy. This has become the normal way of generating power from the wind, and a network of actor practices has developed around this dominant mode of wind energy utilisation.² However, recent developments to promote distributed solar energy utilisation through PV installations integrated into the structure of buildings is another example of a new and quite distinct pattern, nested within the wider incipient renewable regime, itself a relatively small part of the encompassing electricity regime as a whole. Conversely, the electricity regime itself may be seen as nested within a global energy regime organised primarily around the extraction, global transport and thermal combustion of fossil fuels.

¹ New technologies often precede the definition of the functions they will serve. To give a contemporary example, the function of mobile digital photography is currently being defined.

² This is in contrast to the vertical axis designs favoured by some governments at the early stages of modern wind energy innovation, and also in contrast to off-grid, smaller wind energy concepts advocated by others (Gipe, 1995).

The relative status of these particular power technology regimes (e.g. in terms of market share or future expectations by investors) will have an influence on developments in the energy regime at higher levels of aggregation. Some of these 'regime' examples (i.e. wind and PV) actually represent only niche practices and concepts when looked at from the higher perspective of the electricity regime as a whole, since they enjoy neither the institutional nor the market dominance that is a defining feature of the regime concept. Clearly, there is a need carefully to distinguish in any given context between what constitutes the 'nested' and the 'spanning' regime, and to be quite precise in the empirical application of the concept of the socio-technical regime.

Membership of socio-technical regimes

The present focus on the governance of technological transitions requires an explicit focus on the role of agency both within and beyond the regime. In particular, there is a need to think systematically about the empirical boundaries and inter-relationships bearing on regimes at different levels. At root, socio-technical regimes are produced and reproduced by networks of state, civil society and market-based actors and institutions. Take, for example, the regime that supplies water to urban and suburban areas of Europe. In this case, the regime rules and practices relate to a centralised system of water supply through pipes, meeting statutory quality standards, and funded by the regulated charges made to households and other end users. This is reproduced by a network of water companies, capital equipment suppliers, manufacturers of biological and chemical treatments, economic and environmental regulators, households and other water users, consumer groups, government ministries, trade and professional associations, education and training establishments, and so on. All of these actors contribute in some form or other to the operation of the regime by which water reaches the taps of households and firms. As such, all may be considered, to some extent, to constitute 'members' of the water supply regime.

It is clear that the regime is not a homogenous, clearly-bounded entity. However, as this water example illustrates, the question of regime membership is itself complex and problematic. Many members are to some extent also actors in regimes other than water supply. In the specific context of water, some regime members are more tightly networked together than others. That is, the exercise of their agency in the functioning of the regime is more *intensive* than others, and their interests and objectives tend to be more influential on the direction taken by the regime. Clearly, water utility companies are key actors in the practical functioning and evolution of the water regime. They operate key technologies and they make key investment decisions. Households might also appear to be intensively involved, in the sense that practices at household level create the daily demand for water. Households are also the primary source of revenue for water supply companies. But household involvement is mainly *passive*. Households are 'price takers', rarely engaged directly in shaping the rules and operation of the water supply regime. Their influence is most evident in the guise of aggregate demand projections, constructed by the water companies and others in managing the regime and planning change.³ Government agencies play a more formative role in the operation and development of the water regime by setting standards and procedures for planning, safety, quality and pricing. They can therefore be seen as more directly involved in constituting the regime than households. In this

³ Some sociologists argue that we need to deconstruct this passive consumer demand in order to understand water regime transformation (Hand et al., 2003). Changing lifestyles and technologies in the home, for instance, must be problematised, according to this view, and brought into regime development in a much more active capacity. The benefits of efficient washing machines can be lost if offset by patterns of consumption (e.g. popular conceptions of cleanliness) that lead to households washing smaller loads more frequently.

way, it is clear how institutions and their inter-relationships reflect and reinforce the exercise of agency on the part of different actors in any particular regime, and so condition the degree of regime membership.

The discussion so far argues that one way of delineating network boundaries empirically is by analysing the degree to which different actors contribute to the functions that reproduce a regime. We see that regime membership is a relative notion and can be independent of the frequency of economic and other transactions. Those actors who contribute intensively will be core members of the regime. Those actors whose involvement is less intensive will be peripheral members of the regime. Typically no single core member embodies all the elements needed to constitute or reproduce a regime. Although several members may be necessary to the proper functioning of the regime, none alone are sufficient. The crucial determining factor in the effective operation and development of the regime lies not simply in the agency of the individual core members, but in the norms and procedures governing their structured relationships and interdependencies.⁴

The recognition of these structured relationships highlights the arena within which the *strategic* exercise of agency is played out. The role of strategic competition between core members of a regime is vividly illustrated in the field of public health. Here, governments are dependent on pharmaceutical and biomedical industries as key components in the incumbent socio-technical regime. These industries are in turn dependent on government for licenses to market products and services and, in some countries, also as a major purchaser. The operation and development of this regime, thus depends on the effective interplay of these interdependencies. Strategic games emerge around issues such as the prioritisation of different public health objectives, the allocation of resources to contending research and development options, and the regulation of associated safety issues, pricing structures and intellectual property rights. The development of the regime as a whole is played out through active interplay – and sometimes highly adversarial negotiation – between core regime members such as government departments and industry associations. The influence of others, such as regulators, patient groups, the medical profession in this highly charged arena depends on how intensively they contribute to ‘normal’ regime functioning.

This issue of strategic interaction within the regime – and the differential levels of agency enjoyed by core and peripheral regime members – is especially acute in the construction of the ‘guiding visions’ which characterise, rationalise and reproduce the developmental trajectory taken by a regime (van de Ven et al, 1989; Rosenberg, 1994; Kemp and Rotmans, 2001; Berkhout et al, 2003). Different core members will have different ideas and interests bearing on regime development, will exert varying degrees of influence on the construction of these guiding visions and deploy their resources strategically to those ends. By analogy with the idea of ‘appreciative systems’ in policy analysis (Marsh and Rhodes, 1992), strategic interactions reflecting the agency of individual actors (rather than the regime as a whole) can exercise a crucial conditioning influence on these visions.

At times when the normal functioning of the regime is problematic or under stress, peripheral members or outsider actors may be able to intervene with their ideas to greater effect. Under such circumstances, criticisms of regime effectiveness or function appear more reasonable, and debate can be fruitfully opened up. At other times, when regimes are not under such stress, then such opening up is more difficult. Indeed, the way regimes service socio-technical functions can serve to close down the scope for alternative configurations. Regime stress is brought about through the

⁴ Note that this idea is borrowed from the power-dependency theory that lies at the heart of policy network analysis in political science (see Benson, 1980 and Marsh and Rhodes, 1992).

greater articulation of challenging selection pressures, but which are often weak and incoherent. Sometimes, however, the intensity, salience and articulation of certain pressures (e.g. the declining profitability in the current way of doing things, or growing public alarm at the social consequences) induces stress in the regime and opens up windows of opportunity for non-members of the regime to intervene. These occasions are rare.

Socio-technical regimes as social structures

Given the interactions and interdependencies of regime members, it is unsurprising that the literature tends to stress the stability of socio-technical regimes and the rarity of systems innovations (Sahal, 1985). Regime inertia means that regime members tend not to look at familiar problems in a new light or to innovate according to a new vision and rules. Indeed, core regime members often resist change that is considered to threaten the benefits they receive from the *status quo* (Christiansen, 1997). Regimes consequently tend to channel their own development along technological trajectories that are path dependent, and which tend to transform the regime very slowly through an accumulation of incremental changes. This is compounded by the way regimes become increasingly institutionalised, in the sense that social systems like the science system, finance, legislation, training, technology standards, market structures and so forth, tend to entrench regime development by becoming enrolled in its reproduction. The difficulty of realigning such institutions with promising new niches can be a major impediment to their breakthrough into the mainstream (Perez, 1983). Infrastructures supportive of the incumbent regime, and the co-evolution of interdependencies with other regimes (e.g. suburban housing and the private motor car), can act to lock regime development deeper into historical trajectories.

As with many 'structural' accounts, the problem with this regime picture is that it says little about the conditions under which change occurs, or about the switches that may occur between regimes. Any ambitions towards transition management, say, whilst rightly recognising the many structural features of regimes, will also need to analyse and seek out sites of agency within and outside these structures.

Regime shifts or successions clearly have occurred in the past. Who knows, perhaps one day an organic food regime may displace the trajectory of intensive agriculture that has dominated these last decades. Perhaps the energy regime will be transformed by wide-scale adoption of distributed renewable energy systems oriented towards the provision of efficient energy services, rather than maximising bulk sales of energy units. The point, however, is that we need to understand how regimes come to be replaced or radically transformed if we are to sense the likelihood of such scenarios. We need to analyse the processes that enable the exercise of agency in such regimes. In particular, we need to be clear about precisely how, and under what conditions, networks of actors both within and outside the regime can successfully affect a process of deliberate, purposive change.

Socio-Technical Transformations

Despite their relative stability, regimes change. Given the breadth of empirical scope, the variety of regime members, and the structural characteristics of regimes, radical changes are likely to proceed through a complex and unique history of interrelated events. In cutting into such complexity it is helpful to have a relatively straightforward heuristic to fall back upon, in order to help organise one's thinking.

With this aim in mind, we adopt a quasi-evolutionary perspective on the fundamental processes that shape regime transformations.

A quasi-evolutionary model of regime transformation

We understand regime change to be a function of two processes.

1. Shifting selection pressures bearing upon the regime.
2. The coordination of resources available inside and outside the regime to adapt to these pressures.

The governance of regime transformation can be organised through intervention in these two realms. It may seek to address the form, intensity, articulation or orientation of the selection pressures that act on target regimes. Alternatively (or complementarily) it may address the quality and distribution of adaptive capabilities, including the capacity to mount a co-ordinated response and the availability or resources (such as finance, legitimacy or competence) to support these responses. In this sense, policies such as environmental taxation, negotiated agreements, and regulations seek to promote more sustainable configurations through favourable modifications to the selection pressures felt by a regime. Broadly speaking, this is 'back-end' governance that operates through regulatory or fiscal systems. Policies such as R,D&D, environmental management systems, foresight exercises, and capital allowance grants, on the other hand, tend more towards the reshaping of regime adaptive capacity. This 'front end' governance intervenes in the innovation system, in a way advocated by Constructive Technology Assessment. We now elaborate each of these approaches in turn.

The articulation of selection pressures

Conventional economic analysis for the governance of transitions towards more sustainable technology, tends to focus on those forms of pressure which operate visibly at the level of the firm, such as pricing, competition, contracts, taxes and charges, regulations, standards, liability, profitability, skills and knowledge. Analysis at the level of the socio-technical regime, on the other hand, includes such factors, but goes beyond them to consider less economically visible pressures emanating from internal institutional structures, changes in broad political economic 'landscapes', or wider socio-cultural trends. These can be directed at specific regimes, such as the anti-nuclear movement. Or they can be more general, like the ebb and flow of environmentalism as a popular concern in society. Trade associations and industry lobbies are just as involved in the public realm as environmental NGOs in pushing for different patterns of future development. In the energy sector again, for instance, many different actors are promoting visions for a 'hydrogen economy' (Rifkin, 2002). Such activity is significant because it has some bearing upon public policy processes, discussions about long-term strategies in industry, areas of interest to venture capitalists, and so forth. In short, debates in the wider civil society serve to frame the functional reproduction of socio-technical regimes.

Other pressures can derive from social change, which is not targeted at any specific regime, but which can bring about selection pressures on regimes. Examples might include demographic shifts, such as the aging populations of some European countries, or economic migration. Another might be the rise of consumer culture based on the individualistic definition and satisfaction of needs, channelled through an expanding consumption of commodities (Leiss, 1978). A further example might lie in the rise of a neo-liberal model of globalisation with more mobile capital and the

deregulation of markets. All these features of the wider political and economic 'landscape' can create important selection pressures for technological regimes. Often these pressures are weak and incoherent, but at other times they become stronger and more coherently articulated.

The examples of selection pressure introduced above operate at a relatively high empirical level: the changing ideology of political and economic elites; the cultural deepening of consumerism; a greening of public attitudes to consumption, and so on. Of course, incumbent regimes face competitive pressures from other regimes too. This is the more conventional sense in which firms are understood to be involved in systems innovation. The coal-fired power technology regime has been under increasing pressure from the combined cycle gas turbine regime, for instance. In other cases, pressures might 'bubble up' from below, from innovative niches that are not yet so established as to constitute a regime. The transition management approach to governing regime transformation recommends this strategy: the purposeful creation and temporary protection of desirable, niche alternatives which can then be used to seed regime changes (Rotmans and Kemp, 2001).

Without at least some form of internal or external pressure in the broad and diverse senses discussed above, it is unlikely that substantive change to the developmental trajectory will result. However, selection pressures of the kind used as illustrations above are pervasive in post-industrial societies. There is typically no shortage of such pressures – of one sort or another – acting on a regime, many pushing in opposing directions. In practice, it is therefore not the existence of such pressures that is decisive. Instead, it is what we term the *articulation* of pressures for any given regime transformation. This comprises two elements.

First, there is the extent to which selection pressures are oriented coherently in a particular direction. As suggested, different pressures may often act incoherently to promote different forms of response, and so may tend to 'cancel out'. An example might be the conflicting influences on the development of renewable electricity generation in UK energy during the 1990s exerted by falling consumer prices on the one hand, and Government financial support on the other. Another might be the conflicting pressures acting on the global prospects for genetically modified crops, as embodied in strongly positive government and industry commitments in the USA and certain other major exporting markets, contrasted with intense consumer resistance and wider institutional opposition in important import markets such as Europe and Japan.

The second element in effective articulation lies in the processes which render these pressures explicit and translate them into a form that prompts and enables a response by the regime. Here, climate change can be offered as an example. It has taken many years for a scientific consensus to emerge (IPCC, 2001a and 2001b). This scientific consensus stands at the base of international agreement to cut carbon emissions has been reached, and signatory nations are developing their own policies and taking action to move towards lower carbon regimes. This process of identifying, translating and highlighting an environmental pressure is essential to its effective articulation with socio-technical regimes such as those in the electricity supply and private and freight transport. Elsewhere we have discussed some other less well recognised modes of articulation, and their associated pressures (see Berkhout, Smith and Stirling, 2003). Table 1 reproduces a range of different types of selection pressure, and for each illustrates some governance processes through which they might be articulated for the regimes in question.

Table 1: Regime selection pressure and their articulation.

Cause of selection pressure	Example	Articulation processes
The creation within niches of novel socio-technical configurations for meeting a social function.	Putting the organic farming vision into practice, and the spur this gives to mainstream industrial agriculture to become more sustainable.	Measures that support the niche, such as: Grants to create organic food niches. Establishing organic growing training programmes. Niche market creation (e.g. public procurement, green consumerism).
An innovation that seeds a transformation in a 'spanning' regime.	The impact of high-levels of wind turbine capacity on the structure and operation of the electricity system.	Measures to support expansion in the nested regime, such as: Price supports for wind energy. Strategic investments in infrastructure changes suited to wind energy. Environmental NGO campaigns for wind expansion.
The spur to innovation felt through competition from another socio-technical regime serving the same or overlapping markets or social functions.	Competition between the different electricity technological regimes: coal; gas; oil; nuclear; and renewables.	Measures which promote technological or resource diversity, such as: Incentives to support a balanced portfolio of energy technologies and systems. A regulatory framework for fair competition between regimes, within environmental constraints.
The competition between different 'visions' for the future held by a variety of social actors, some of whom are more directly embedded within the regime than others; and the different power resources they have to pursue these visions.	Current contention over the use of 'science-based' risk assessment versus more broad-based 'precautionary' approaches to chemicals regulation.	Measures for civic debate, such as: Broadening participation in the framing of chemical regulatory decisions. Introducing contentious visions into processes of policy negotiation. Local protests against chemical establishments.
The generation of changes in the social landscape that put the regime in tension.	The liberalisation of energy markets in the EU.	Measures to understand the implications for regimes, such as: Monitoring social trends. Foresight exercises. Dissatisfaction with the poor fit of the regime with modern life.
Politically-motivated debates targeted at changing a range of problematic socio-technical regimes.	The current public debates and campaigns over genetically-modified foods in the EU.	Measures that create informed debate, such as: Public participation in policy agenda setting (e.g. identifying which regimes are effected by debates). Dissenting voices. A well resourced, educated, vibrant civil society

Articulation processes happen through coalitions of resource interdependent actors acting within and beyond established institutions of governance. They may or may not include regime members. Proactive industry leaders may, for example, push the case for changes within regimes. As with the delineation of regimes, so the identification of articulation processes is an empirical task. Whichever ways selection pressures become articulated, they only form one half of the regime transformation equation. The other factor is the capacity available either within the incumbent regime or outside it, to respond adaptively to that pressure.

Adaptive Capacity in Regime Transformation

Some regimes have the capacity to respond more readily to selection pressures than others. We refer to this feature as the *adaptive capacity* of a regime. One way of characterising regime adaptive capacity is with reference to five 'functions' that contribute to the reproduction of technological systems (Jacobsson and Johnsson,

2001).⁵ These functions are reproduced in Table 2. The better able regime members are to carry out these regime functions, the better the regime as a whole will be able to respond to selection pressures. Regimes can be seen as being reproduced along trajectories that are in part determined by selection pressures being applied to them. The more intensive or threatening these pressures, the greater will be the resources devoted to defending the regime. This might be one understanding, for instance, of current efforts within the electricity supply regime to respond to climate change concerns by establishing techniques for the sequestering and environmental disposal of carbon from fossil fuel power stations.

We draw a distinction between capability and capacity. Capability is qualitative, and relates to the precise way regime functions are fulfilled. Capacity is more of a quantitative term. Adaptive capacity is about how much of any given adaptive capability one can bring into play. The regime membership might, for example, guide search directions (a capability) but in only limited areas at any given time (a capacity constraint). All else being equal, the more adaptive regimes would be those whose membership is able most effectively to reproduce the regime in the context of

Table 2: How different governance activities contribute to adaptive capacity.

Adaptive capability functions	Example	Governance contribution to that function
<i>Creation of new knowledge:</i> the main source of variety in technological systems.	Research into fuel cell technology and its applications.	Public R&D. Education and training policy.
<i>Influence over the direction of search processes among users and suppliers of technology:</i> the articulation of supply and demand is seen as critical to the perceived costs and benefits of regime switching.	The way a growing coalition of actors are building expectations for a future hydrogen economy, and how this influences research and industrial agendas.	High-level foresight exercises. Organisation of conferences with prestigious business speakers. Environmental lobbying which weakens faith in incumbent regime and raises the profile of others.
<i>Supply of resources:</i> These include capital, competences and input materials as well as political resources that support the legitimacy of a regime.	Ability to bring together the finance, technology, and fuel supply infrastructure to roll out local biomass energy businesses at more and more rural locations.	Public underwriting of risks and soft loans. Grants (public and private). Secondment of expertise to new initiatives.
<i>Creation of positive external economies:</i> This is a pivotal characteristic. An example is the formation of socio-technical networks that provide 'spill-over' effects by reducing uncertainty, reducing the cost of information, accessing tacit knowledge and sharing costs.	The entry of a large industrial investor into a hitherto niche activity, such as biomass energy, boosting the status of the niche (e.g. credit rating with financiers, interest from other firms). Or, the way development of wider biomass supply infrastructures makes it easier for new biomass energy firms to enter the market.	Public pressures on companies to seek out more responsible corporate activities. Publicity about the success of a growing niche. Study tours and sponsoring visits to projects. Infrastructure support. Favourable regulatory environments.
<i>Formation of markets:</i> Innovations rarely find ready-made markets, which therefore need to be stimulated or created afresh. Market formation is related to the marketing efforts of firms, as well as the regulatory and other influences on the shape of markets.	PV technology has developed through a series of niche markets, such as satellites, remote power supply, calculators, parking meters, and, more recently, household systems.	Green consumerism. Public procurement. Fiscal policy (impacts for relative prices).

Adapted from Jacobsson and Johnson, 2001

⁵ The technological system concept is very similar to the socio-technical regime concept.

selection pressures. Over time, we would normally expect more adaptive regimes to succeed and those with less adaptive capacity to be subsumed or substituted.

However, it may be that in some cases it is not the membership of the incumbent regime itself which proves decisive in providing these functions. Sometimes, when the adaptive capability of the regime is weak, it can be outsider groups who build up the functions that can generate the alternatives needed for change. For instance, an important source of change may be innovative niches, which pioneer new ways of constituting and satisfying a social and economic demand. Effective adaptive capabilities can respond to pressures by opening up novel niche practices as alternatives to the incumbent regime in some form or other (e.g. new technologies, new appraisal criteria). Sometimes it is outsiders that are able to marshal the resources needed to put the alternative vision into effect.

In this way a successful niche can challenge the dominance of the incumbent regime, and members of the incumbent regime may struggle to seize the new opportunities. Under such circumstances, the niche is exerting selection pressure. This point warns us not to limit our search for adaptive capacity to the membership of the incumbent regime. Indeed, depending upon the types of change being articulated by the different selection pressures, the greatest capacity for adaptation and change may rest in nascent networks of capable actors beyond the membership of the incumbent regime.

From the perspective of the effective governance of transitions to more sustainable technologies, the focus of interest lies in the potentiality for change, wherever this may arise. In this way, the notion of adaptive capacity transcends the regime, extending to cover the potentiality provided by hitherto peripheral or external actors radically to augment or transform capabilities. Any empirical analysis of the networks that uphold or challenge regimes will therefore need to use a wide canvas to review how actors contribute to regime functions.

Negotiating pressure, coordinating adaptation

Although the articulation of selection pressure and the provision of adaptive capacity are conceptually distinct, the actors and institutional settings involved in each need not necessarily be separate empirically. An actor such as an environmental regulator may simultaneously be intervening to articulate a selection pressure and also make efforts to help co-ordinate the resources necessary for adaptation. This empirical overlapping of the functions fulfilled by different actors is particularly acute in the contribution to the search direction function of adaptive capacity, since the articulation of a selection pressure may serve to open up new search directions for innovation.

The ability to articulate a salient pressure for regime change and / or build up an influential adaptive capability will usually require interactions and resource flows between actors, through networks or coalitions that may or may not involve the incumbent regime membership. The facility with which this can be achieved will depend upon each actor's negotiating position, defined in terms of their own interests and ideas, the degree to which they have power over others, and the centrality of the functions they perform (relative to the collection of selection pressures and adaptive capacities overall). Coalitions of prime movers are needed, who are 'technically, financially and politically so powerful that they can strongly influence the development and diffusion process' (Jacobsson and Bergek, 2003: 5). The greater the extent to which pressures for a particular form of change diverge from the norms and rules of the incumbent regime, the more acute become issues of power. Even if the

membership is not active in its opposition to change, the regime may nevertheless present a considerable degree of inertia that must be overcome.

There are some potentially significant parallels here at a fairly high level of abstraction between the way that socio-technical regimes are conceived and the more general conceptual ideas of what constitutes governance. As with the technological regime, governance itself is exercised through relatively stable sets of norms, rules and practices that prioritise public issues, take decisions on them, and implement those decisions. Governance means something wider than the state (just as regime is wider than industrial sector). It looks beyond the ideology, institutions, structures and instruments of the state (such as ruling parties, industry ministries, parliamentary procedures, environmental regulators, public spending, policy instruments, and so on). The state is embedded within wider networks in civil society and market systems. Like regimes, this involves interaction between actors in networks. Moreover, because regimes and governance are both social phenomena, they will also involve processes of consent, dissent, inclusion, exclusion, and power between the different actors involved.

It may not always be possible to negotiate and coordinate a powerful coalition for a clearly envisaged change. Attempts may meet with partial success. Indeed it may be that such deliberate attempts do not emerge at all, in the sense that change occurs through a process of uncoordinated interactions between shifting, poorly articulated selection pressures and struggling adaptive capabilities. Clearly, the context in which regime transformation arises, both in terms of the nature of the incumbent regimes and the governance situation, is important for the processes of change that actually unfold. In the final section of our chapter, we use our quasi-evolutionary model of change as the basis for a simple typology of transition contexts.

Transition Contexts

As the relative strength of different selection pressures shifts, and adaptive capabilities change, so the transformation process will change too. Analysis begins when we relate this context of regime transition to general patterns of transformation. The art for any transition management project then becomes one of recognising which context prevails at any point in time and space, and which drivers offer the best leverage for guiding change in a desirable direction at that point. As we have already discussed, the articulation of selection pressures is one source of leverage. Building adaptive capacity is a second lever.

Transition contexts can be mapped using the two dimensions of change introduced earlier in this chapter. The first dimension measures whether change is envisaged and actively coordinated – either at the level of the regime membership or on the part of some higher level governance process – in response to prevailing selection pressures, or whether it is the emergent outcome of the normal behaviour of regime members (involving no new mechanisms of coordination).⁶ This dimension seeks to distinguish between regime transformations that are essentially intended and deliberate and those that are the unintended and contingent outcomes of historical processes. An intended regime transformation would be guided by influential actors within the regime or by overarching networks of governance arriving at a common diagnosis concerning shortcomings in an incumbent regime. It would require some level of agreement on the appropriate prescriptive measures and their objectives, given the prevailing selection pressures as they are currently articulated and

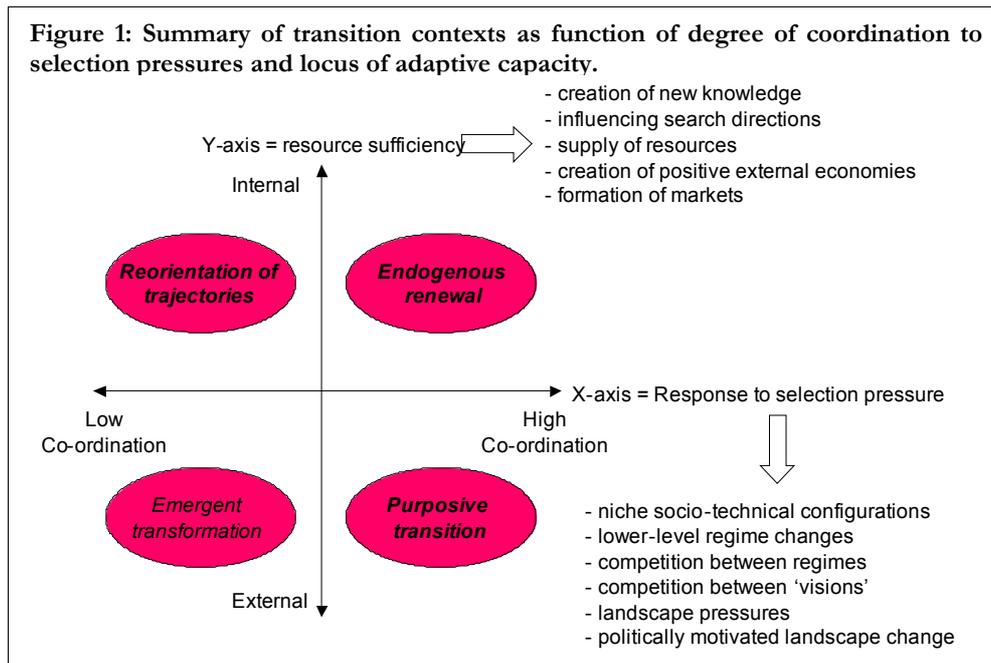
⁶ In making this distinction between low and high levels of coordination we want to move beyond a simple planned/market-based dichotomy, to take account of more complex processes of the social regulation of technologies that involve not just the state, but also other social actors including civil society organisations and consumers.

understood. Of course, this says nothing about the desirability – for instance the genuine sustainability – of the particular intended measures, objectives or outcomes. For present purposes, the point is simply that the regime membership itself, might choose to coordinate adaptive capacities to protect the interests of regime members. This dimension of co-ordination is blind to the merits of motives or outcomes, measuring simply the degree of intentionality and co-ordination involved in driving a given transition.

The second dimension concerns the degree to which the response to selection pressure is based on resources available within the regime (or which can be co-opted by the regime), or depends upon capabilities that are only available outside the regime. The *locus* of the capabilities to innovate and adapt is therefore important to the nature of the transformation process. If the resources required for transition are available internally, then change is likely to be more incremental and structural relationships within the regime are less likely to be overturned. If the capacity to adapt is highly constrained by the lack of resources internally, then the likelihood of major structural change increases. The *coordination of actors / locus of resources* framework gives rise to a fourfold mapping of transition contexts (see Figure 1).

As discussed in more detail in an earlier paper (Berkhout, Smith and Stirling, 2003) the four quadrants produced in this framework represent schematic ‘ideal types’. Comparisons and contrasts between the elements of each transformation can be made against real-world regime transformation processes and our understanding of the variety of processes consequently improved. As has been suggested above, whatever the nature of the selection pressures and the responses to them, the four transition contexts may all play out operationally at different levels of aggregation. In attempting to make more explicit the distinctions between possible transition contexts, we hope to develop a richer and more robust basis for understanding the different processes of socio-technical transition and the associated opportunities for normative policy intervention.

This typology lends itself to two types of heuristic use of relevance to wider governance processes oriented towards the fostering of more sustainable technologies. One use is as an analytical device, and the other as a normative tool. First, in analytical mode, we can take as a starting point that prevailing circumstances and established governance practices are conditioning a particular ‘default’ transition context. The task of analysis by means of this heuristic then becomes one of identifying the *particular* type of transition that is underway. Assuming that the likely outcome of this transition is judged to be desirable – in this case in terms of environmental and social sustainability – then governance measures might be oriented towards assisting the committed process of change in a fashion that is as timely, efficient or socially acceptable as possible.



The second approach starts the other way around. This rests on an appraisal process which concludes that a committed prevailing situation is unlikely to yield a desirable outcome. The appraisal process must then identify some more desirable outcome and the heuristic scheme used in normative mode to guide understanding as to how best to achieve this. In this case, the appropriate governance strategies are not those that best assist some prevailing process of stasis or change, but those which best foster the particular transition context identified in appraisal as being appropriate to achieving a desired outcome. So, for instance, if a prevailing situation of 'endogenous renewal' is identified to be oriented towards an unsustainable outcome, then the aim of governance might be to foster instead a 'purposive transition' to a more radical solution. This is obviously a more challenging mode of usage for any conceptual scheme, placing greater demands both on the taxonomy and on whatever governance measures may be deemed applicable.

The normative approach also begs the question, who is leading the governance strategy? As we concluded in the preceding section, governance is the result of interactions in policy networks, embedded in historically-shaped institutions, and lobbied by coalitions of actors with different views. In practice, the typology presented here could help each of these actors interpret the transition context in which a target regime operates. They could then use this intelligence to inform their strategy for influencing the governance of that regime.

Having discussed the governance possibilities of transition contexts, it is time to describe each of them. A series of stylised examples – emphasising the energy sector for the purposes of effective comparison – are used here to provide more concrete illustration.

Endogenous renewal (coordinated response, internal adaptation)

Endogenous renewal arises in the context of regime members (firms, supply chains, customers, regulators) making conscious efforts to find ways of responding to a perceived competitive threat to the regime. In the terms of our typology, the pressure to change the regime is clearly articulated and there is a high coordination of response, based on resources originating within the regime. However, as has been

discussed, given that innovative activity is shaped from within the regime itself, it will tend to be steered by the prevailing interests and values, cognitive structures, and problem-solving routines of the incumbent regime. Decisions over future technological choices will be guided by past experience. Thus the transformation process will tend to be incremental and path-dependant. Looking back over a long period of time the transformation can appear radical, but it will have come about through an alignment of smaller changes.

An example of this kind of process may be found in the progressive scaling up of the thermal capacity of steam-generating plant over the course of the twentieth century. Constituted by a multitude of individually minor organisational and engineering innovations, the result was a radical transformation in the character of the electricity regime (Hughes, 1987). Likewise, investment in flue gas desulphurisation plant as a response to concerns over acid emissions (Boehmer-Christiansen and Skea, 1991), or the development of carbon sequestration techniques might also be taken as examples of endogenous renewal. In either case, the long-term implications, were the processes of change to be deep-seated and sustained, would be one of incremental regime transition.

From a governance perspective, there are both analytic and normative approaches – as defined above – to consider. In the first, analytic approach, we understand governance (the collection of measures identified in Tables 1 and 2) to be content to enable and contribute to a process of endogenous renewal. The sustainable transformation of the regime is therefore likely to occur through incremental environmental performance improvements and an accumulation of marginal improvements in social equity.

In the second, normative approach to governance, the challenge for a regime that already fits this endogenous renewal type of context, is to identify how to steer transformation in a more sustainable direction. The regime membership demonstrates an ability to coordinate their response to selection pressures. They also have the capabilities to adapt successfully in terms of maintaining regime structures intact. If the regime is highly adaptable, governance strategies might best be focused on the coherent articulation of ecologically sustainable and socially equitable selection pressures.

Re-orientation of trajectories (uncoordinated response, internal adaptation)

Some socio-technical regimes exhibit an intrinsic property of ‘systemness’ (Rosenberg, 1994:216-17) in their processes of change while at the same time being highly unpredictable. In these regimes, trajectories of change may be radically altered by internal processes without being associated with discontinuities in the actors, networks and institutions involved in the regime. The stimulus for the radical re-orientation is a shock (from outside the regime or within) impacting upon the technological system. The response, however, is formed within the incumbent regime. In the electricity sector, an example of this kind of regime change might be seen with the advent of wide-scale adoption of combined cycle gas turbines, especially in the UK (Islas, 1997). This radical transformation in the technical and operational characteristics of generation systems was not widely anticipated or intended, but arose through the conjunction of a series of uncoordinated technological opportunities, changes in market regulation and obstacles facing alternatives such as coal and nuclear generation. However, the adoption of gas turbines was managed within the dominant electricity generation regime, rather than being a development imposed from without.

Analytically speaking, governance that contributes to good adaptability functions internal to the regime, under situations in which the sustainability challenge is poorly

articulated and responses uncoordinated, will lead to regime transformations that reorient trajectories. Governance measures such as boosting appraisal capabilities, the innovation and adoption of cleaner technologies, favouring greener consumption within the incumbent regime, and so forth could radically transform the trajectory of development of the regime. However, if the selection pressures are poorly-coordinated, then the reoriented trajectory of development could take off in an unanticipated direction.

Using this transition context in more normative mode, then a governance strategy for intervention is facing a situation in which the incumbent regime is well furnished with the resources for the committed process of change, but where this is not necessarily the case for the particular orientation of change favoured in the governance strategy itself – for which the selection pressures may be incoherent. Thus the selection pressures will probably represent the best place to begin governance strategies: working with the ‘back-end’ of regulatory systems (regulations, taxes, and so on) to try and create a selection environment that induces the regime to apply its resources to more sustainable ends. In effect, this would push the regime from a reorientation of trajectories context over to an endogenous renewal context, and so regime transformation would ultimately move incrementally towards sustainability.

Emergent transformation (uncoordinated response, external adaptation)

Many classical regime transitions have an apparently autonomous (though socially-constructed) logic. This type of transformation in our typology arises from uncoordinated pressures for change and responses formed beyond the incumbent technological regime. The technological cycles described in Kondratiev’s long waves have this character of emerging from highly complex social and economic processes that lead to the emergence of technologies with pervasive impacts. Many of the examples used in the technological transitions literature have this form (Christensen, 1997). Their origin is typically in scientific activity often carried out in universities and small firms operating outside existing industries (Dosi, 1988). These transitions can be observed, but there appears very little basis *ex ante* to distinguish between those alternatives that will ‘catch on’ (Mokyr, 1991:276) and those that will not. In the energy sector, a long term example is provided by the series of ‘energy successions’ governing the dominance of different ‘primary fuels’ running over a period of three centuries or so from wood, through coal, to oil and gas. Contemporary examples of these kinds of technologies with major disruptive potential include information technology and genetically-modification technology in the food and pharmaceuticals sectors. The impacts of these technologies have of course been across many different technological regimes – in this sense it is incorrect to speak of a single transition, but of many parallel transitions stimulated from a common technological basis and shaped by regime-specific configurations of interests and goals. It is also clear from the GM example that the environmental impacts (as perceived by key actors and institutions) of these emergent transitions may remain quite uncertain even some way down the process of path creation.

From our governance perspective, this case pertains in an analytical sense to situations where there is no coordinated response to poorly articulated selection pressures. Key adaptive functions are developed beyond the membership of the incumbent regime. Under such a governance situation the transformation will be emergent. Consequently, it will be difficult to anticipate clearly what form of sustainable development the transformation will take.

If taking a more normative perspective, and confronted with a regime exhibiting the properties that fit this emergent transition context, then the governance challenge is open. Governance strategies can be built up which inject greater coherence into the selection pressures and regime response. Alternatively, or at the same time, governance strategies can be pursued which build up the relevant adaptive capabilities. If key adaptive functions are built up internally, within the regime, then the situation (analytically speaking) will move into the endogenous renewal quadrant, and transformation towards sustainability will be incremental. Should adaptive functions be developed beyond the incumbent regime, as they were before intervention, then (analytically speaking) the governance situation will move towards the purposive transition quadrant, and transformation will fit that process, i.e. potentially following a process of more radical leap towards sustainability (see below).

Purposive transitions (coordinated response, external adaptation)

While emergent transitions have an autonomous quality, we seek to distinguish these from purposive transitions which have in some senses been intended and pursued to reflect the expectations of a broad and effective set of interests, largely located outside the regimes in question. A good example of this type of transition is the history of civil nuclear power in the industrialised world. Nuclear power was widely regarded in the 1950s and 1960s as a critical technology with the potential to generate broad economic and political (military) benefits. A common narrative was developed which involved a series of technological transitions from uranium fuel cycles (with the light water reactor as the main conversion technology) to plutonium fuel cycles (with the fast reactor being the conversion technology). Scientific, policy and industrial interests were co-opted to this vision to form a powerful interest grouping which was typically in strong contention with establish interests within the incumbent socio-technical regime of the electricity system itself. This latter example shows that this form of transition – imagined, planned and partially executed – does not necessarily generate social and environmental benefits.

Transition management is the transformation of a socio-technical regime guided primarily by negotiation between social actors from beyond the regime. Analytically, this governance strategy fits the present ideal type purposive transition. Key to the transition management project is that these social actors have a greater role in forming the socio-technical response to the co-ordinated pressure for change. Obviously, this demand for change has to be mediated by the regime actors. Transition management is also the outcome of a deliberate attempt to change the regime according to a consensus guiding vision (hence selection pressures are highly articulated). Thus, if our schema is accurate, the transformation process is most likely to be that of purposive transition.

Of course, as our discussion of governance strategies has indicated, the transition context for any given socio-technical regime need not be fixed. Contexts may change, and the proposition in this chapter is that any change in context will influence the pattern of regime transformation. It will also alter the governance opportunities available to different social actors. The heuristic typology presented here is intended to help us understand and frame appropriate questions for the regime transformation processes in a series of different governance situations (i.e. the kind of transition context the governance situation is creating) and / or aid policy-makers intervene in an informed way under given transition contexts. The governance of regimes can be understood as altering the given context of selection pressure and adaptive capacity, and thereby modifying transformation processes, in terms of pace and/or direction.

Summary and Conclusions

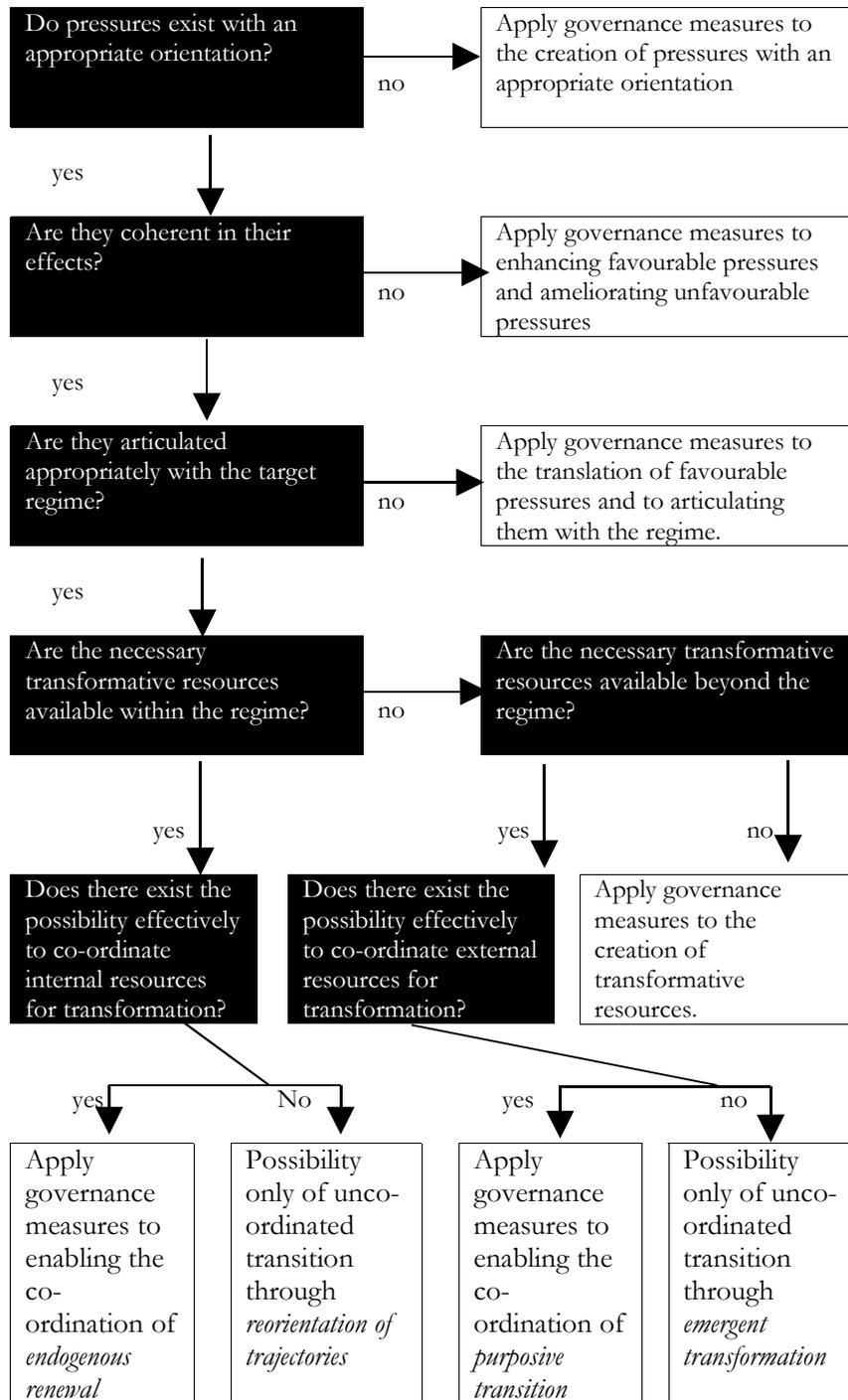
The currently burgeoning perspective focusing on technological regimes presents a fresh and potentially highly fruitful way of cutting into the challenge of industrial transformation – promising more profound and pervasive insights than the preceding approach focusing on the greening of individual industrial sectors. An industrial sector focus is concerned primarily with the firms involved in the production and supply of certain goods and services. A regime focus is concerned with the network of actors and institutions clustered around the fulfilment of social and economic functions. Sectors and regimes nest and overlap – and may be coterminous – but they are not the same.

As a consequence of this, transformation is understood to be change that is mediated by the practices of institutionally embedded *networks* of actors. Regime membership rests upon the intensity of involvement of actors in the reproduction of regime functions. Change might be sought by a specific coalition of actors, but it will need to be carried through within networks of actors possessing the wherewithal to adapt the incumbent regime or create alternatives. By ‘carried through’ we mean change will need some *coordination* and *resources* between actors. This will be built upon active processes of support and / or passive processes of acceptance in order to generate sufficient *consent* to put change into practice. However, not everyone will agree to change, there will be dissenting voices. At times, such dissent can make a useful contribution to the innovation of regimes by opening up search directions and redefining the multiple criteria by which regime performance is assessed (beyond ubiquitous economic criteria). Regimes, by definition, have a tendency to close down options and introduce stability.

The legitimate authority to push change through, or the resources available to build consent, or to raise informed dissent, or even to block change, will depend upon power relations across the networks of actors involved. Governance processes provide an arena for debates about how best to ‘manage’ or modulate regime transformation for sustainable development. We have suggested that governance can seek to influence or even guide regime transformation in a number of ways. These are summarised in general terms in the ‘decision tree’ scheme in Figure 2. We stress that this diagram is intended only as a summary of the argument, and we would caution against any inclination to use it in a mechanistic, unreflective fashion.

In particular, we argue that the task of governing successful sustainable technological transformations might be significantly assisted by distinguishing the role of the *articulation* of selection pressures acting on the regime and the twofold elements of *adaptive capacity* (the provision and coordination of resources for adaptation). These two dimensions to the governance of regime transformations form the key axes along which can be plotted different transition contexts. In this chapter we have put forward the hypothesis that the processes and outcomes of a regime transformation depend upon the transition context prevailing at that time. Contexts in which selection pressures are highly coordinated will go through a different process of change compared to those situations where selection pressures are uncoordinated. Moreover, if the functions that contribute to adaptive capacity are found predominantly within the incumbent regime, then transformation will differ from contexts in which such functions derive primarily from beyond the regime membership. Endogenous renewal, reorientation of trajectories, emergent transformation and purposive transition are four ideal types of transformation that unfold under these different transition contexts.

Figure 2: A Heuristic Decision Tree for Normative Governance of Regime Transformation



In any given instance, these particular forms of transition – like the substantive technological options themselves – may variously be seen in different quarters as desirable or undesirable objectives. Such judgements will be arrived at in any given case by active political deliberation. The role of a heuristic scheme such as this, is to reveal the variety of structural choices with which governance debates are faced and so help prompt fruitful questions and shape possible responses. The essence of sustainability lies in the recognition of agency in social choices about technological futures. It is by focusing directly on the challenges posed by different contexts for the

transformation of technological regimes, that we may hope to do a better job of fulfilling the pressing social and environmental imperatives of sustainability.

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