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Preparing for socio-technical transitions: Opportunities and challenges for policy design

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Abstract - Effective policy mixes are expected to accommodate uncertainties in the future policy context by being flexible and adapt over time in expectation of a range of anticipated and unanticipated conditions. In response to shifts in the future policy context, while policy changes can manifest as increments to status quo over time, policymakers may also need to face the possibility of making major policy shifts to enable the transition into more appropriate policy regimes. In the context of socio-technical transitions, the switch to new policy alternatives can be facilitated by incorporating new policy actions into the suite of current policy strategies early on, which can also help accommodate the long lead-times on some decisions and actions. This paper is a conceptual piece that focuses on integrating policy design thinking into the crafting of conscious policy choices and mixes to enable socio-technical transitions while considering the likely changes in the future policy context.

1. Introduction to socio-technical transitions

The concept of transitions management has gained prominence in the last decade to explore "a range of possible pathways for change" (Farelly and Brown, 2011; Meadowcroft, 2009). Transitions can be defined as 'a gradual, continuous process of structural change within a society or culture' and are complex, spread over long timeframes, involve multiple actors and occur across multiple levels (Rotmans et al., 2001). Transitions require a process of "system innovations" by different participants and fundamentally change both system structure and the relation among the participants (Loorbach and Rotmans, 2006; 2010; Van der Brugge and Rotmans, 2007). After their initiation, certain innovations can stagnate and reinforce the status quo leading to a 'lock-in' or 'system breakdown' due to the failure of the innovation to sustain, or a 'backlash' due to lack of large-scale adoption of the innovation (Kemp et al. 1998; Rotmans et al. 2001; van der Brugge and Rotmans, 2007). However how the transition to new regimes occurs has been an area that has not been studied in detail (Bettini et al., 2014).

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Transitions operate through interactions across multiple levels of social structure. This includes a 'landscape' or macro level which includes exterior social and physical environment factors such as demographics, macro-economic conditions and the natural environment that influence the dynamics at the lower levels i.e. regimes and niche; 'regime' or meso-level is the general set of rules that orient and coordinate the activities of the actors and social groups that reproduce the various elements of socio-technical systems (Geels, 2011). These rules include shared beliefs, lifestyles, regulations, institutions, contracts and cultural values. Components of a particular regime such as markets, technology, policy, industry, and culture, have their own set of unique rules but interact with each other and can be potentially affected by changes in other groups. Finally, 'niche' or micro-level is are protected spaces such as research and development laboratories, incubators, demonstrator projects, or niche markets where innovation is led by motivated individuals that can differ from the regime (Rip and Kemp, 1998; Geels, 2002, 2005; Frantzeskaki et al., 2012). Actors in 'regimes' or 'niches' often have no control over the 'landscape' developments.

In order to undertake necessary transitions, the future policy context can be considered to be 'reasonably predictable' – such as cycles of commodity price swings or periods of inflation and unemployment, demographic changes such as aging of populations or increasing urbanization for which reasonable time-series data exist, others are affected by policy events and futures which make them unpredictable (Wardekker et al. 2010; Watson et al. 2015). Policy responses for such rather predictable future policy contexts, often tend to be incremental in nature (Anwar et al., 2013). However, when policymakers are faced with unanticipated changes in the policy context, an incremental change in policy response might not be fast enough to deal with the consequences or anticipate these unpredictable events (Roggema et al., 2012).

In the process of socio-technical transitions, the changes from status quo policy regime can also face resistance by certain sections of stakeholders, making any radical changes in the policy mix difficult even if new policy objectives are employed (Kern and Howlett, 2009). For example, technological innovations for sustainability would need to compete with existing technologies that have been assimilated into the socio-economic context and attempt to fit through processes of "learning, coercion and negotiation" over time (Rip and Kemp, 1998; Christiansen et al., 2011).

As per the theory of policy change put forth by the punctuated equilibrium model, a stable regime is characterized by the institutionalization of the 'reigning orthodoxy'. Any adjustments to a stable regime are primarily made by a closed group of actors within the policy subsystem. Over time, there may be departures from what the current regime intends to achieve and its actual achievements on-ground, creating anomalies (Wilder and Howlett, 2014). When anomalies accumulate and are not able to be anticipated or corrected by the current regime, experimentation is undertaken to accommodate

and address these anomalies within the current regime. If this effort fails, the regime becomes exposed to criticism by new actors challenging the current regime and policy actors face the pressure to adequately address the anomalies (fragmentation of authority). When this debate enters the public arena and involves the larger political process, contestation happens. After a period of time Institutionalization of a new regime can occur when proponents of a new regime secure positions of authority and alter existing organizational and decision-making arrangements to institutionalize the new subsystem, paradigm and regime (Hall (1993); de Vries (2005); Oliver and Pemberton (2004); Howlett et al., 2009). This paper presents an overview of opportunities and challenges for policy design in undertaking policy change and preparing for socio-technical transitions.

2. Policy design and policy change

Policy design is conducted by diverse actors with the prime objective of improving policymaking and outcomes by anticipating the impacts of policy actions and consequently determining courses of action to be followed (Dryzek, 1983). Some policy scholars argue that the nature of policy design is positioned between being "a construct and an adaptation of policy" (Lejano & Shankar, 2012). This means that while policy design can be considered as a noun i.e. related to the most suited outcome, it can also be considered a verb, as a process aimed at the convergence of diverse actors and perspectives towards the achievement of a common set of goals and objectives (Howlett and Lejano, 2013).

Typically policies emerge as 'bundles' or 'mixes' of policy tools through policy change processes, and some elements are added or removed over time (Howlett and Rayner, 2013). A policy mix comprises of some abstract or conceptual goals, specific program content or objectives and operational settings or calibrations (Hall, 1993; Cashore and Howlett, 2007; Howlett and Cashore, 2009). A key challenge while designing policies for the future is to operate in a space where there are pre-existing policy mixes that have developed over time, often through a series of incremental changes such as 'layering', 'drift', 'conversion' or reformulation such as 'redesign' (Thelen, 2003; Streeck and Thelen, 2005; Van der Heijden, 2011; Howlett and Rayner, 2013).

To prepare for and/or respond to a changing policy context as part of socio-technical transitions, policy mixes can emerge in various forms over time, through both intentional and unintentional interventions by various policy actors. Socio-technical transitions are also influenced by the nature of actors and advocacy coalitions shaping the policy context (Markard et al., 2015). Owing to this political nature of transitions, incremental changes to current policies are argued to be more suitable (Lindblom, 1959; Deyle, 1994; Heazle et al., 2013). On the other hand, some scholars argue that incremental approaches (despite their political acceptability) might be inadequate to deal with major changes in the policy context and call for facilitation of anticipatory policy efforts for transitions by

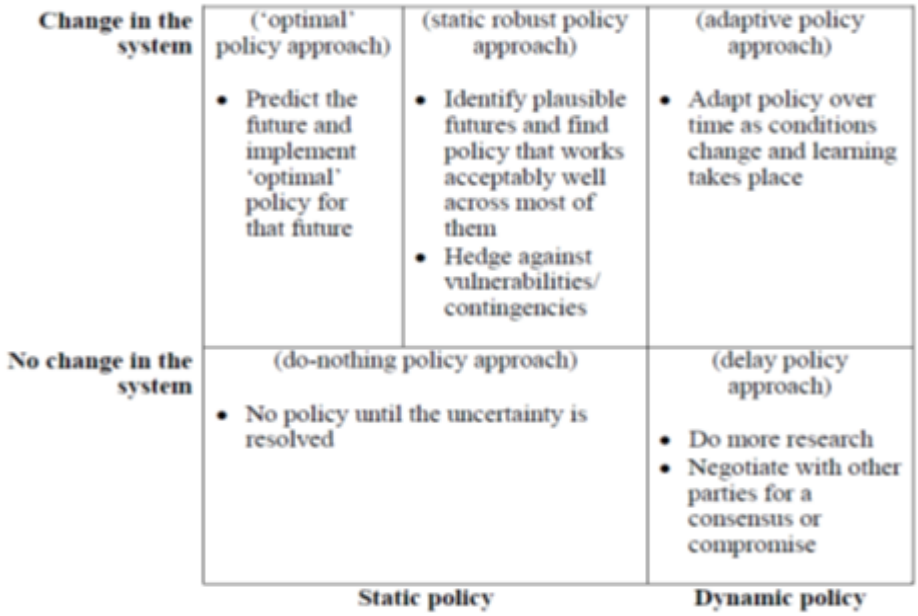
incorporating these into the suite of policy alternatives early on (Howden et al., 2010; Park et al., 2012). Policy design for socio-technical transitions is also affected by ambiguity i.e. "simultaneous presence of multiple frames of reference about a system among different actors" (Kwakkel et al., 2010).

Hall's (2003) work on policy dynamics and policy change based on the three-order model, remains the most quoted piece of literature on studying policy change. However, policy scholars in the last decade have also drawn attention to the perils of studying policy change as an aggregate variable limited to these three orders. These scholars have argued that such aggregation can lead to a rather myopic view of the more complex and granular processes of policy change that may go beyond the incremental change vs. paradigmatic change classification (Howlett and Cashore, 2009).

Augusdinata (2008) discusses that from a policy design perspective policy approaches under conditions of uncertainty can be classified based on the *nature* of the decisions being made (one-time/ static or dynamic) and the type of *actions being* taken to address uncertainty. This broad classification can generate five policy approach categories (Figure 1). This includes:

1. Do-nothing: There is no policy until the impending uncertainty is resolved.
2. Delay policy: Maintain status quo while efforts are made to reduce or better characterize uncertainty by gaining more knowledge.
3. 'Optimal' policy approach: Policymakers use 'best estimate' models to choose an 'optimal' policy.
4. Static robust policy approach: A robust policy or one that performs 'reasonably well' across most likely plausible future scenarios is chosen.
5. Adaptive policy approach: involves adapting the policy over time as conditions change and learning takes place. Policies that are rigid or less flexible to incorporate elements of change in their design or implementation run the risk of not meeting their end objectives. Hence there is a need for policies to be 'adaptive' under conditions of change (Swanson et al. 2010).

Figure 1: Policy approaches under uncertainty (Augusdinata, 2008)



Similar to Augusdinata (2008), Walker et al. (2013) highlight four ways (overlapping to some extent) in which policies/plans could address deep uncertainty:

1. Planning for the worst case scenario: which is likely to be expensive and not equipped to deal with 'surprise.'
2. Resilience: accepts the likelihood of an adverse future but focuses on quick recovery.
3. Static Robustness: targets at reduction of adverse impacts across a range of possible range of conditions
4. Dynamic Robustness: allows policy/plan to change over time as the conditions change.

Following the model of policy change set out by Cashore and Howlett (2007), six elements characterizing a policy can be assumed to change. These elements include changes in policy ends and changes in policy goals. Changes in policy ends further included change in policy goals (general ideas that govern policy development), change in policy objectives that it formally aims to address and change in policy settings (on the ground requirements of the policy). Changes in policy means include change in instrument logic i.e. norms guiding implementation preferences, change in mechanisms i.e. types of instruments that are being utilized and change in calibrations i.e. the specific ways in which the instrument is used. Such changes, however, may or may not bring about increased or enhanced coherence of policy elements. Howlett and Rayner (2007) argue that the degree of coherency between policy goals and degree of consistency between policy means should be studied on a case-by-case

basis. Policy goals are considered coherent if they logically relate to the same overall policy aims and can be simultaneously achieved without significant trade-offs. Policy goals are incoherent if they contradict the previous goals. Policy tools are considered consistent when they complement each other and work in combination towards meeting a policy goal, and inconsistent when they work at cross-purposes (Kern and Howlett, 2009).

The essence of the search for solutions to a policy problem entails discovering not only which actions are considered to be technically capable of addressing or correcting a problem but also which among these is considered to be politically acceptable and administratively feasible (Howlett et al., 2009). The search for a policy solution will usually be contentious and subject to many conflicting pressures and alternative perspectives and approaches, frustrating efforts to systematically consider policy options in a rational or maximising manner. The positioning of actors, for example, plays a key role. Understanding the ideas and experiences that these actors bring to policy formulation, and the contexts within which they operate can help explain why some options gain considerable attention while others are ignored.

While the concept of designing policies to be adaptive or flexible to accommodate change is considered desirable in principle, there are challenges in operationalizing adaptive policymaking. Van der Pas et al. (2012) draw attention to the institutional challenges in implementing adaptive policies, primarily owing to their increased costs, complexity and time-intensiveness compared to conventional static policy approaches, making it difficult for policy practitioners to justify them in the present date, even though the benefits might offset the costs in the long-run. Additionally, changes suggested to the original policies and plans in the process of being robust and adaptive might require the original policy design to be altered significantly in some cases, which may not be politically or socially desirable.

3. Policy design and socio-technical transitions

For policy design under uncertainty, it is important to utilize design processes that can generate outcomes that are proportionate to the level of change in the policy context. For example, policy responses towards addressing climate change impacts have largely focused on policies and programs for accommodating change rather than creating alternatives in a planned manner (O'Brien et al., 2012). Kivimaa and Kern (2016) suggest that a policy process of "creative destruction" is critical to socio-technical transitions, i.e. creation and development of the new policy mix and destabilization of the existing one. Under uncertainty, however, creation of an optimal new policy mix is challenging as the policy design is limited to pre-determined scenarios that do not cover the broad spectrum of uncertainty. For example, climate change is a complex policy issue and requires policymakers to

design policy responses considering climate uncertainty (Klein, 2003). Changes in the climate and some of their impacts are likely to be non-linear, decreasing their predictability for decision-making (IPCC, 2007).

The policy literature remains rather inconclusive on whether under conditions of uncertainty, policymakers prefer to make incremental changes to existing strategies or it provides an opportunity to innovate. Heazle et al. (2013) argue that under conditions of high complexity and uncertainty incremental approaches i.e. adjusting along the margins of business-as-usual strategies are better able to address political conflict and deploy policy responses to adapt to the problems "we know we have now" and can control while "factoring in a margin for them becoming worse".

In what is probably the most well-known approach to the subject, Lindblom (1959), for example, argued that "successive limited comparison" resulting in incremental change is a realistic and fruitful method of policy analysis in circumstances of 'bounded rationality' or when policy-makers encountered difficulties identifying and assessing future policy challenges and pitfalls. Incrementalism, however, has been criticized for lacking a clear goal orientation and being inherently conservative to large-scale change or innovation, following undemocratic decision-making (confined to senior policy actors), promoting short-sighted solutions due to lack of systematic analysis and mostly applicable in stable environments (Hayes, 2013).

While some policy mixes for socio-technical transitions may be consciously designed in anticipation of a new policy context, others could emerge gradually through a process of incremental changes to the current policy mix. One of the common ways in which changes to current policies are made is via layering wherein new policy ends and means are simply appended without altering the current policy structure (Howlett and Rayner, 1995). Drift refers to when policy goals have changed while previous policy instruments remain intact, and conversion refers to when attempts are made to change policy instruments to address additional self-evolved goals which result in misdirected policy efforts (Howlett and Rayner, 2008). Layering can also lead to Conversion wherein the policy is directed towards new goals (Falkenmark, 2004; Hacker 2004). When anomalies arise within current policy mixes, policymakers can also attempt to 'patch' or restructure existing policy elements instead of suggesting novel policy arrangements (Howlett and Rayner, 2013).

On another extreme of policy design is transformation that can be undertaken as a deliberate process with the intent of achieving a specific goal(s) and it can also occur as an "unexpected or unintended outcome of a process or event" (Nelson et al., 2007) or when faced with 'surprise' (Lindenmayer et al., 2010; Wardekker et al. 2010). Incremental responses, on the other hand, largely remain in step with existing systems and are therefore better suited to circumstances in which changes in both the

environment and technology of policy is minimal (Kates et al., 2012). A key barrier to transformations, however, is that these challenge existing beliefs, norms and regimes through technological innovations, institutional reforms, behavioural and cultural changes among others. There are also uncertainties related to for example, how the climate, socio-economic and political environment unfolds in the future, costs of transformation and of any unintended impacts (Rickards and Howden, 2012; Kates et al., 2012), possibility of maladaptation, 'over-adapting' and building capacities to transform. Learning and leadership play a major role in overcoming barriers to transformation (Heifetz et al., 2009; Tschakert and Dietrich, 2010).

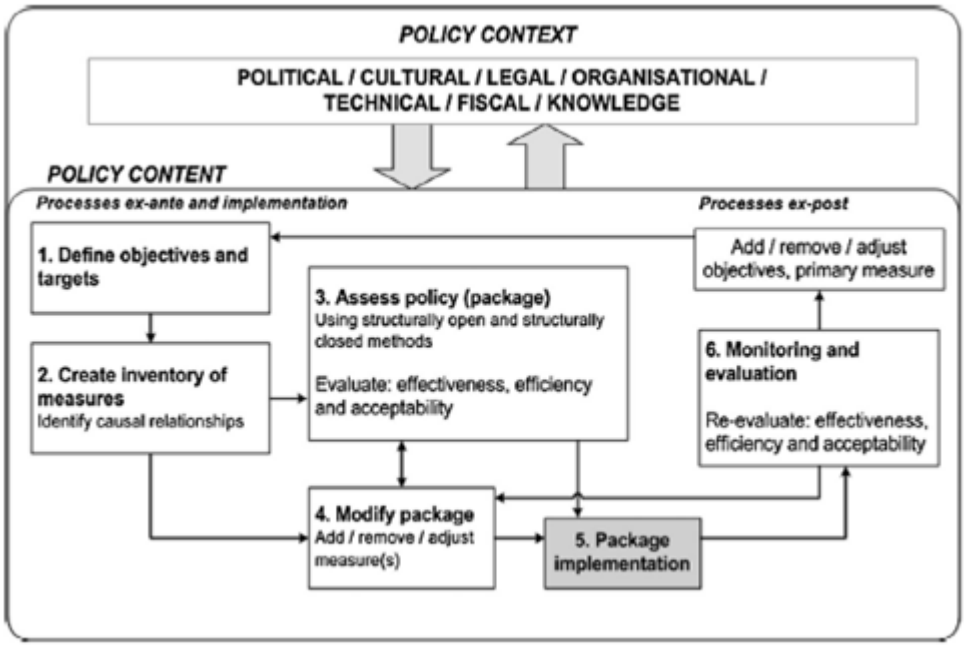
Given the high costs of some of policy transitions and transformations, uncertainties of risks and benefits enabling social contexts including leadership and availability of acceptable options and resources for actions are critical. The switch to transitions and transformations can be facilitated by incorporating these into the suite of risk management strategies early on, which can also help incorporate the long lead-times on associated policy decisions and actions (Howden et al., 2010; Park et al., 2012).

4. Emerging avenues for design thinking for transitions

4.1 Policy packaging

The concept of policy packaging has been gaining attention in recent literature to assist the choice between diverse policy alternatives. Policy packaging aims at implementation of a combination of measures instead of individual measures and aims at increasing efficiency and effectiveness by enhancing synergies and reducing inconsistencies among the measures (Taeihagh et al., 2013; Howlett and Rayner, 2013). Building on the policy design frameworks proposed by Taeihagh et al. (2009; 2013) and Givoni et al. (2013), Justen et al. (2014a) reconceptualized an idealistic model of policy packaging and identified the key steps to this design process. Evaluation and re-adjustment of policy packages created from an inventory of policy instruments to meet defined policy goals and objectives are critical to the process of policy packaging (Figure 2).

Figure 2: Idealistic model of the policy packaging process (Justen et al., 2014a)



Howlett 2014 and Howlett et al. (2015) highlight that except the case of new designs in new policy domains, policy design literature demonstrates that phenomena such as layering, drift and conversion are very common. Howlett and Mukherjee (2014) conceptualize a spectrum of policy design moving from conscious efforts towards policy change such as "smart" patching and ultimately to those which are less intentional and involve poor design such as "stretching" (simply expanding the elements of current policy mixes spread over decades to cover new goals) and "tense layering" (severe case of inconsistent layering and mismatch between new and old policy goals and means) (Figure 3).

Figure 3: Spectrum of policy design (Howlett and Mukherjee, 2014)

4.2 Policy experimentation

Management of transitions involves experimentation with alternative means of transitions towards possible futures that are linked to long-term sustainability goals for the society and learning (Loorbach and Rotmans, 2006). These experiments can have the ability to overturn existing policy regimes when the opportunity so arises. In the late 1990s, research on policy design remained rather stagnant as it was assumed that changes in policy design "predetermined policy specifications". In recent years, however, the policy design field has revived its role and ability in consciously exploring

improved designs depending on the policy context through the greater use of experimentation, flexibility in design and policy mixes among other things (Howlett, 2014). The concept of adaptive policymaking (policies adapt over time as conditions change and learning takes place) is also based on operating on available best scientific information till new knowledge comes up, or active i.e. consciously experimenting with policy alternatives to identify better strategies as new conditions emerge (Walter, 1992; Swanson et al., 2010).

For governments however it may not be very appealing to appear in a mode of active and 'constant experimentation' for certain policy issues as it runs the risk of the public not taking the specific program seriously or trying to influence the outcomes to suit their interests, especially if it calls for investments (Peters, 1998). If policy change involves significant costs, it is likely to motivate policymakers to change and thus increase the 'stickiness' of existing policies (Callander, 2011). Policymakers might however often be hesitant to undertake or announce policy experiments owing to issues of 'accepting uncertainty' (Stoker, 2010). Even after the launch of an experiment, corrective back iterations into the experimental design can continuously occur, especially when the experiment was a failure in practice or was not completely institutionalized (Wilder and Howlett, 2014).

4.3 Network-centric policy design

While network analysis has been used extensively for analysis of the relations in society in general and study of policy actors and networks, it's use in policy design has been limited (Taeihagh 2017). In recent years the interest in better understanding the complexity of policy problems has increased, particularly around issues relating to the design space and temporal factors. However, the disconnect between this understanding and appreciation and access to systematic tools, methodologies and frameworks to better understand the trade-offs of policy alternatives is concerning. This is not to say that there have been no attempts in development of visualisation, record of rationale or decision support tools, in fact, approaches such as issue-based information systems (IBIS) and a number of problem-structuring methods have been developed over the years with the aim of addressing these shortcomings (Rittle and Webber, 1973; Van der Lei et al. 2011; Mingers and Rosenhead 2004).

In network-centric policy design, the focus is on examining policy instruments, their interactions and configurations in policy mixes. The first step is to develop an inventory of policy instruments and define a criteria for differentiating among them followed by classification of interaction among policy instruments, and visualisation and analysis of their interactions before ranking of the policy instruments using the user defined criteria (Taeihagh et al. 2013; Justen et al. 2014a)[2]. In addition, use

[2] For illustration examples and detailed explanation of how to identify, characterize and classify nodes and relations see Taeihagh et al. (2009; 2013). For detailed explanation of how decision support systems can be integrated with policy instrument networks see Taeihagh et al. 2014.

of the network-centric approach in conjunction with decision support systems enables visualization and analysis of policy mixes, conducting sensitivity analysis and can provide an interactive environment in which real-time feedback is provided to the user while carrying out policy design and examining the trade-offs between different alternatives (Taeihagh et al. 2014).

Network-centric policy design facilitates increasing the granularity of the designed mixes beyond the six elements of policy mixes (Cashore and Howlett, 2007) by adopting policy instruments as the building blocks of policies in an integrated bottom-up approach and by using network structures to capture interaction among policy instruments (Figure 4) and the interactions of policy goals through development of 2-mode networks for selection of instruments in various policy mixes based on the defined criteria for assessment. This approach is systematic and helps increasing transparency of how and why a policy mix was selected as well as creating organisational memory.

When a policy is already in place as opposed to situation in which an entirely new policy is being packaged, the first step is to map the existing goals and instruments in place and then examine the potential new goals and policy instruments that are being considered. Mapping the goals and instruments facilitates examining the policy mix for potential issues such as drift, conversion or layering and whether patching is possible or an entirely new design is needed (Howlett, 2014; Howlett et al. 2015).In addition, using decision support systems enables to explore alternative policy mixes and consider consequences of issues such as policy failures and delays regardless of the cause, which helps to identify critical components of the policy and examining means for enhancing or changing the mix to improve it using ancillary policy instruments (Taeihagh, 2017).

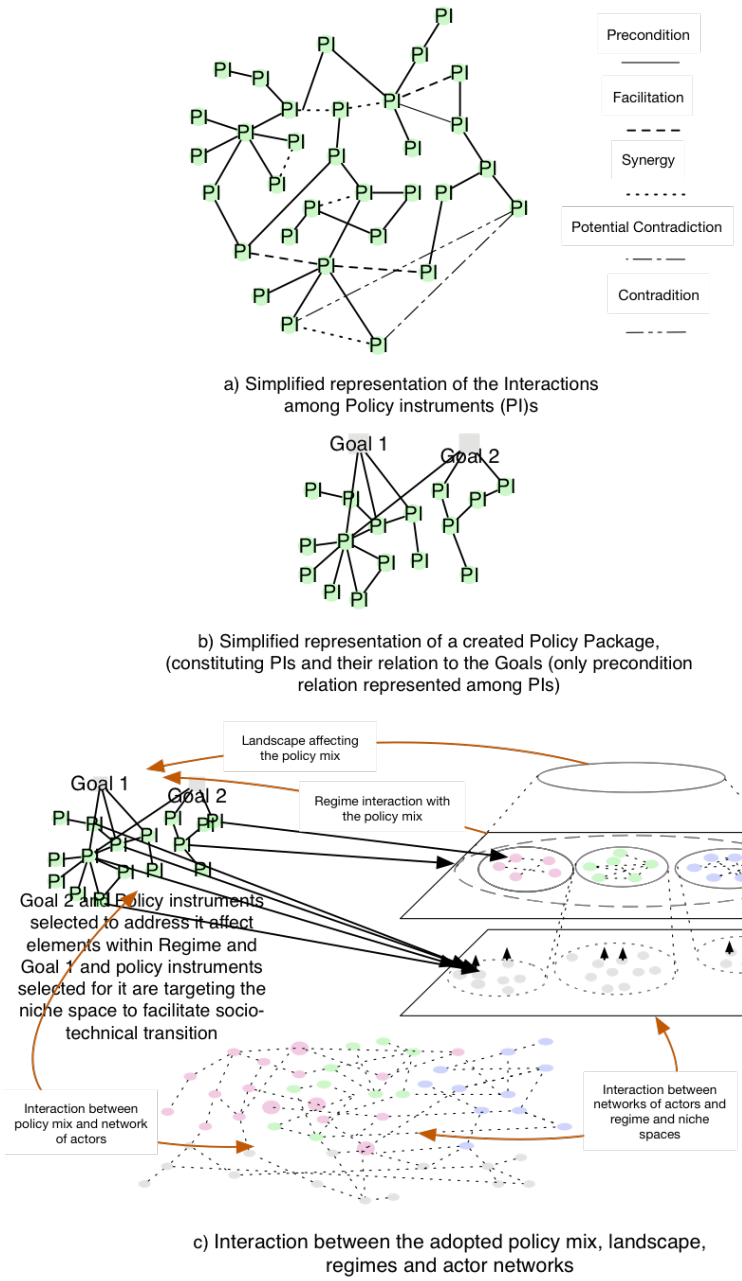


Figure 4 a) Simplified representation of the relations among policy instruments within a multiplex Policy instrument network, b) a selected policy mix, that constitutes two goals and a number of policy instruments, and c) representation of interaction of the selected policy mix in b) with landscape, regimes and actors networks.

In both policy design and transition studies, a major concern is understanding temporal factors and dynamic processes as well as exploring the possibilities to facilitate policy change and transitions (Howlett, 2010; Taeihagh et al. 2009; Nill and Kemp 2009; Geels and Schot, 2007). In both domains, multilevel perspectives of the factors affecting the design of policy mixes and social structures and their interactions have been developed (Cashore and Howlett, 2007; Taeihagh 2017; Rip and Kemp,

1998; Geels, 2002). Besides systematic exploration of the design space, a network-centric policy design approach enables:

- Visualisation and analysis of the policies over time: Policy instrument and policy goal interactions are often complex; also, additional layers of complexity stem from interactions with policy actors, externalities that affect the system as such application of systematic approaches and use of networks to capture and analyse these interactions is useful.
- Sequencing of the policy instruments: Given the importance of temporal factors and the concept of window of opportunity in socio-technical transitions and various policy recommendations based on regime stability and status of technological alternatives and market dynamics (Nill and Kemp 2009), policy sequencing is particularly important due to requiring redesign of regime elements (Howlett et al. 2015). Application of decision support systems can facilitate development of smarter and reinforcing designs and help avoid internal contradictions in the policy mix and to some extent help avoid unintended consequences (Taeihagh et al. 2014; Justen et al. 2014b). Sequencing can help in better consideration of temporal factors such as the time required for policy implementation, the duration of delay from the time the policy instrument is implemented till the effects of the policy are felt and the duration of the effect of the implemented policy to appropriately sequence the implementation of the policy instruments. Furthermore, use of decision support systems enables scaling up the number of policy mixes under analysis and provides the ability to inform the users of such systems of the effect of their decisions on the performance of policy mixes in real-time.
- Evaluation of policy failure: As Figure 4c depicts policy mixes, landscapes and regimes, niches and policy networks have various interactions in any policy problem. Due to these complex interactions many factors can cause policy failures or delays such as: a) policy implementation failures; b) unanticipated consequences of the implemented policies; c) changes to the landscape environment (e.g. a system shocks); d) changes in the position of the policy actors, or conflicts among them; and e) changes in social or political attitudes towards the policy). Network-centric policy design can aid decision-making under high levels of uncertainty as once a policy mix is selected, the consequences of policy failures and delays can be explored regardless of the cause using decision support systems (Nair and Howlett, 2014; 2017; Taeihagh et al. 2014). This facilitates identification of critical components (nodes - representing policy instruments) and consideration of increasing the robustness of the policy by using ancillary instruments or by developing policy responses such as learning mechanisms through piloting and experimentation (van Buuren et al., 2013; Huitema et al., 2016).

5. Discussion and Future Work

Designing for socio-technical transitions is challenging as these transitions are political in nature and are influenced by the nature of actors and advocacy coalitions shaping the policy context (Markard et al., 2015). Owing to this political aspect of transitions, incremental changes to current policies are argued to be more suitable (Lindblom, 1959; Deyle, 1994; Heazle et al., 2013). On the other hand, some scholars argue that incremental approaches (despite their political acceptability) might be inadequate to deal with major changes in the policy context (such as brought by climate change) and call for facilitation of anticipatory policy efforts for transitions by incorporating these into the suite of policy alternatives early on (Howden et al., 2010; Park et al., 2012).

The design intention of policy packaging is to combine policies in a way, that side-effects or unintended effects can be avoided as much as possible, albeit these are known. To do so, these must be assessed in advance using a set of tools and methods such as Cost-Benefit analyses, scenario assessments, qualitative methods such as expert judgment, surveys, multi-criteria analysis, etc. The challenge, however, lies in understanding which of the methods and tools can be used for which purpose and at what stage in the process of policymaking (Justen et al., 2014b).

Governments have a pivotal role as laboratories for policy experimentation and policymakers must continually monitor and learn from experimentation (Moynihan et al, 2012). Experiments have also been useful as a source of evidence for policymaking. However there are challenges in realization of the benefits of policy experimentation in practice, both in relation to ‘meaning’ in terms of understanding the future, and ‘power’ in terms of undertaking related policy action (Nair and Howlett, 2015).

Policy formulation under uncertainty is challenging, given the interdependence and complexity of socio-technical systems. Under conditions of uncertainty, shifts and transitions from status quo policies may be necessitated, considering not only the likely future changes but also the response of the socio-technical systems affected by these changes. Adjustments to a stable policy regime can be influenced by actor relations and networks within the policy subsystem, including policy change for socio-technical transitions and policy implementation at the ‘niche’ level. Several advancements have been made in the study of network-centric policy design in relation to policy mixes and interactions between policy instruments specifically. Network-centric design can enable transitions via analysis of interaction among policy instruments, the ranking of policy instruments and proposed mixes, visualisation and analysis of policy mixes, enabling better policy sequencing and use of decision-support systems to avoid policy failure. Key challenges relate to political nature of the policy process resisting changes to the current policy mix, mismatch between old and new policy mixes, creating an enabling environment for new policy options to emerge competitively and selection of appropriate

policy mixes.

Network-centric policy design can help us explore multiple policy alternatives but uncertainty about the future policy context can limit the ability of policymakers to design appropriate policy instruments and mixes. Apart from empirical and methodological challenges, there may uncertainty owing to institutional barriers for garnering consensus, combining expert judgment, and integrating multiple perspectives (Webster, 2003).

The advantage of the network-centric policy design lies in enabling bottom-up approach to design of policy mixes through use of network concepts. Use of network-centric design enables computational analysis of policies and allows further expansion of the analysis by integration of the design of policy mixes with actor networks, and use of decisions support systems (particularly through use of agent-based modelling approach which itself is suitable for bottom-up design). Moreover, using computable network structures for the design of policy mixes enables is the ability to take advantage of the latest methodological developments in other fields that use networks (e.g. mathematics, biological sciences, social network analysis, engineering etc.) and computational design approaches from fields such as engineering, architecture and computer science that address issues around design and dynamics of complex structures and use networks and computational means for exploring design alternatives.

However, use of such an approach is not without its challenges. A high level of analytical policy capacity is required, which translates to overcoming political and institutional challenges and high degree of transaction costs and access to staff that can use such methodologies or tools, or access to resources to train them (Wu et al. 2015; Milgrom and Roberts, 1990). Moreover, the political aspects of policy design which are often difficult to capture and anticipate cannot be neglected. Thus, in making the choice between plausible policy packages political factors may sometimes override technical competence of these packages. Apart from limitations in terms of financial resources, there can also be challenges in interpreting complex policy packages as prioritizing between multiple plausible instruments and their combinations is a constant challenge (Justen et al., 2014a).

Some of the avenues for enhancing the application of network-centric policy design for design of policy mixes for sustainable socio-technical transitions are as follows.

As illustrated in Figure 4c, actors within the socio-technical system, interact within regime and niche spaces and influence the adoption of policy mixes and are targeted by the policy mixes. In previous studies, such considerations were carried out indirectly by including criteria such as levels of institutional complexity and public unacceptability (Taeihagh et al. 2013); However, it is possible to map and analyse the actor networks and simulate their interaction with the policy mix. For instance,

by conducting network analysis and use of simulation it is possible to measure and visualise the varying strength and centrality of actors and examine how changes to these networks over time can affect policies and how policies can potentially change the strength of different actors.

By using decision support systems it is possible to fine tune the design of policy mixes and specific instruments for specific geographical and governance contexts. It is possible to further integrate actor networks with geographical contexts to better understand the effects of policy mixes on specific target groups in specific sectors and/or within geographical boundaries.

Acquiring data and expert judgments for development of policy mixes in is challenging when it comes to gathering information about policy instruments, their attributes and interactions, actors within the niche and regime spaces. Use of approaches such as crowdsourcing can increase the number and rate of participation of crowds in the policy making process as well as facilitate acquisition of data and judgments about policy mixes from expert and non-expert crowds (Aitamurto and Landemore, 2016; Prpic et al., 2015).

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