Great expectations: the promises and limits of innovation policy in addressing societal challenges

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Great expectations: the promises and limits of innovation policy in addressing societal challenges

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Abstract

In the policy discourse on societal challenges it has become common to think of innovation policy as the universal tool for addressing societal challenges. However, we argue that innovation policy has limits to what it can do, and for it to remain a useful tool for tackling societal challenges, it is necessary to re-assess its role. Thus, this paper addresses the following research questions: What are the theoretical implications of the augmented expectations of innovation policy to deliver system change, what role can innovation policy play in contributing to system change, and what conditions this role. Linking to the literature on wicked problems and radical innovations, we differentiate between disruptive and progressive system change, and show that the potential role of innovation policy differs between these two types of change. Acknowledging both the potential and limitations of innovation policy, we make a proposition for how an ambitious innovation policy contributing to system change may be conceived.

Keywords: Innovation policy, System change, Societal challenges
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1 Introduction

Innovation policy has become somewhat of a panacea to address global grand challenges, which are often described as wicked problems (Boon and Edler, 2018; Schot and Steinmueller, 2018). The reason for the prominence of innovation policy is that the nature of grand challenges, and more generally wicked problems (Head, 2022; Levin et al., 2012; Rittel and Webber, 1973), is seen to require an important level of change, often referred to as deep-structural, systemic, socio-technical change (Kuhlmann and Rip, 2018; Mazzucato, 2016). This type of change has been addressed in various academic communities, but probably most prominently in the transitions branch of innovation studies, where innovation is seen as a key driver of such deep-structural systemic change. One of the core assumptions is that innovation, and its institutionalization and diffusion, is at the heart of radical societal change. Therefore it is crucial to study, theorize and provide policy guidance about the governance of innovation (Borrás and Edler, 2020; Edler and Fagerberg, 2017; Kuhlmann, 2001). However, the meaning of innovation has been broadened, ranging from innovation as commercialization of knowledge in products towards the notion of 'system innovation', referring to socio-technical transitions, which constitute a fundamental system change (Geels, 2002; Grin et al., 2010).

This shift from innovation as a distinct socio-technical phenomenon towards innovation being used as a synonym for industrial, sectoral or societal change is problematic because such a stretch of concept may reduce its analytical strength, in particular in understanding how innovation contributes (or fails to contribute) to broader processes of system change. At the same time, the conflation of innovation and system change hinders policy makers and policy scholars from talking about transition policies that are not at all connected to innovation policy in the classical sense.

In this paper, we aim to disentangle these developments and put forward clearer boundaries and definitions of innovation, innovation policy, and the role of innovation policy for system change. By elaborating on the essence of these notions, we hope to contribute to strengthening the role of innovation policy for addressing societal challenges, and respond to our research questions: What are the theoretical implications of the augmented expectations of innovation policy to deliver system change, what role can innovation policy play in contributing to system change, and what conditions this role?

We proceed by first analyzing in Section 2 the evolution of expectations for innovation policy in its dominant paradigms – linear, system oriented, and transformative innovation policy. Then, in Section 3, we discuss the theoretical implications of the augmented expectations for innovation policy to deliver system change. In Section 4, we elaborate on the potential and limitations of innovation policy to contribute to system change. Here, drawing on literature in political science, we differentiate between two types of system change – disruptive and progressive system change. We conclude in Section 5 with a proposition for an ambitious innovation policy that contributes to system change based on a summary of innovation policy's potentials and limitations.

2 Innovation Policy Perspectives – Towards Increasing Expectations

Several different perspectives of innovation policy exist that entail substantially different implications for policy making and governance. In recent years, scholars have proposed different typologies capturing the rationales for innovation policy and their different levels of ambition (or lack of it) with regard to grand challenges. Schot and Steinmüller (2018) argue for three distinct framings of science, technology, and innovation (STI) policy: frame one with a focus on economic growth and mitigating market failures; frame two, focusing on national systems of innovation and commercialization of knowledge for international competitiveness; frame three refers to innovation as a means to invoke radical system change to address a diverse range of sustainability challenges. In a similar vein, Weber and Rohracher (2012) make a distinction between structural innovation policies, which focus on optimizing innovation systems for knowledge production, and transformation-oriented innovation policies aiming at more general system change, often concerning whole industries. A slightly different typology of innovation policy rationales was put forward by Edler and Fagerberg (2017) who differentiate between mission-oriented, invention-oriented, and system-oriented innovation policy.

In the following, we will distinguish between linear innovation policy, system oriented innovation policy, and transformative innovation policy, acknowledging that these types do not neatly follow each other and have partly overlapping features (Grillitsch et al., 2021). We will reflect on their basic rationales, definitions of innovation, and, most importantly, how each of these strands addresses the issue of grand challenges.

2.1 Linear Innovation Policy

The 'linear' perspective to innovation policy is largely based on a perception of innovation as "applied scientific knowledge", assuming a linear process from basic research to new products or services (Borrás and Edquist, 2019, p. 30). It was developed mostly in the post-war period and was driven by the expectation that public investment into science and research would significantly benefit the society (Bush, 1945). This perspective took its starting point in the Schumpeterian (Schumpeter, 1934) understanding of innovation, where a clear distinction was made between invention and its exploitation – i.e. innovation. In other words, innovation was defined as "commercialized invention" (Freeman, 1974; Schot and Steinmueller, 2018). Edler and Fagerberg (2017) describe this as 'Invention-oriented' policy, where the focus of policy is on the invention phase, and exploitation and diffusion is left to market forces. More specifically, the primary role for policy would be to support the production of scientific and technological knowledge, through different kinds of research councils and R&D support measures.

Both the linear and invention-oriented policy concepts are tightly connected to the market-failure rationale. While the economic thinking in the post-war period recognized the importance of knowledge production for innovation (Arrow, 1962; Nelson, 1959), it would also emphasize the difficulties associated with appropriating the returns from R&D investment for private actors. Therefore the state would need to intervene both in terms of supporting the public and private creation of knowledge as well as protecting the returns through IPR protection regimes (Edler and Fagerberg, 2017).

In the linear/invention-oriented innovation policy paradigm, the main purpose of innovation is fostering economic growth (Schot and Steinmueller, 2018). However, some definitions also suggest a secondary purpose in providing solutions to societal challenges (Borrás and Edquist, 2019). This duality of objectives is well reflected in the main policy instruments developed and deployed within the paradigm: (a) direct support to both fundamental research and R&D in private entities, and (b) mission-oriented programs for responding to critical societal challenges (Schot and Steinmueller, 2018). Providing direct support for science and R&D is motivated directly by the linear innovation logic and the premises of 'commercialized invention' (Freeman, 1974), whereby scientific research is necessary to make the discoveries that via R&D could later be commercialized. Furthermore, the market-failure rationale would assume that companies on their own are not inclined to invest enough in R&D to bring about the desired technological break-throughs. Therefore state support for knowledge production, either by public or private entities, would be necessary.

The other main policy instrument, mission-oriented programs, is more directly related to grand challenges, being a direct response to what governments would perceive as critical needs in certain policy areas (especially defense, originally). These 'classic' missions of the post-war era were typically science focused and state-driven in their goal-setting. From a grand challenges perspective, these missions were noteworthy, because "/.../ the funding of basic scientific research can be justified in terms of its contribution to specific objectives rather than relying solely on the somewhat vaguer promises about science's long run benefits" (Schot and Steinmueller, 2018, p. 1557).

Notwithstanding this specific type of mission-oriented programs, linear innovation policies were mainly developed with the rationale of economic growth in mind. Potential unintended societal (or environmental) consequences of innovation were largely ignored, and at best dealt with ex-post regulation. Yet, elements of this perspective to innovation policy can still be important components of contemporary policy mixes for addressing societal challenges. This is particularly evident for mission-oriented policy, which, in a modernized form, has regained its prominence as a potentially powerful tool for responding to societal challenges (Mazzucato, 2018; Wanzenböck et al., 2020).

2.2 System Oriented Innovation Policy

The innovation system perspective was born in the 1960s and 1970s based on seminal works of Jack Morton and Christopher Freeman (Godin, 2017) and received momentum in the late 1980's, largely because of increasing attention towards the national institutional contexts as an enabler for innovation and thereby sustained economic growth (Freeman, 1987; Lundvall, 1992; Nelson, 1988). While the national systems of innovation has been the dominant perspective in innovation studies, several other systems strands have developed in parallel, including technological (Carlsson and Stankiewicz, 1991; Markard and Truffer, 2008), regional (Asheim and Isaksen, 1997; Cooke et al., 2004) and sectoral (Malerba, 2004) innovation systems. Furthermore, an important body of work has focused on the processes (activities/functions) within the innovation systems (Bergek et al., 2008; Edquist, 2005; Hekkert et al., 2007). In a recent account from the innovation systems perspective, Borras and Edquist (2019) define innovation as "new creations of economic or societal importance" (p. 16) and systems of innovation as composed of "innovations as such as well as determinants of innovation processes" (ibid. p. 19). As an extension, innovation policy is the "actions by public organizations that influence the development and diffusion of innovations" (Borrás and Edquist, 2019, p. 39).

The innovation system perspective sees the societal role of innovation in contributing to innovation-driven economic growth. In particular, the focus of national innovation systems has been on national competitiveness, creating the necessary structures for enabling a country to enhance its economic power in relation to global competitors. As such, the broader societal challenges beyond economic growth have largely remained outside the national innovation systems thinking, at least until recently.

Accordingly, the innovation policy tools developed within the national systems of innovation paradigm focus on creating linkages between actors in the innovation system and shaping an institutional environment (Edler and Fagerberg, 2017). The goal is to foster interactive learning and thereby innovation. Examples of such policies include cluster programs, science parks, regional innovation environments etc. As such, the policies are more geared towards developing the overall innovation environment than targeting any particular societal challenge. However, more recent discussions have also emphasized the role that systems of innovation can play in relation to societal challenges. For example, Weber and Rohracher (Weber and Rohracher, 2012, p. 1038) describe the role for systemic innovation policies as "creating an institutional environment for firms which is more conducive to their innovative capabilities, creates synergies and spill-over effects and helps them to adapt to transformations of the techno-economic environment". There are, however, several challenges in adapting the 'traditional' innovation policies to responding to societal challenges and transformations, as an important part of the policy tools used in the national innovation system perspective has been inherited from the linear innovation policy paradigm. These policies would traditionally support the technology-push view of innovation policy (Borrás and Edquist, 2019), rather than any broader societal challenge. In particular, the innovation policies from the linear and innovation systems paradigms have been argued to suffer from four shortcomings: directionality, demand articulation, coordination and reflexivity (Weber and Rohracher, 2012).

With regard to directionality, the new generation of mission-oriented policies (Wittmann et al., 2020) can be considered to be part of the innovation system perspective. As the aim of these policies is to provide 'systemic responses' to societal challenges (Larrue, 2021), it requires more sustained and possibly larger-scale efforts, comprising of a mix of different instruments (Kern et al., 2019; Rogge and Reichardt, 2016). This kind of systemic view, coupled with the need for creating a favorable environment for innovation-led change, matches well the overall policy framework within the innovation system perspective. Regarding demand articulation, one could say that more recently there has been a growing interest in demand-side policies, such as innovation procurement. These tools can also be seen as potent instruments for addressing societal challenges (Edquist et al., 2018), allowing for directing public resources towards delivering innovative solutions to concrete problems. At the same time, the policy coordination and reflexivity failures can be much more difficult to address within the linear and national innovation systems paradigm. This constitutes an important limitation for the 'traditional' innovation policy in matching the increasing expectations for contributing more towards solving the societal challenges.

2.3 Transformative Innovation Policy

Transformative Innovation Policy, as the name suggests, is interested in transformation that comes about through system change, also referred to as "system innovation" (Schot and Steinmueller, 2018). It has its intellectual roots in sustainability transition studies (Köhler et al., 2019). Sustainability transitions refer to major shifts in socio-technical systems, which are understood as configurations of

actors, institutions and technologies encompassing the production, distribution and consumption of basic functions in society such as the provision of energy, water, or transportation (Markard et al., 2012). However, the co-evolution of institutions, technologies and actors over time is believed to make socio-technical systems very stable, and innovation therefore often path-dependent and incremental (Fuenfschilling and Truffer, 2014; Rip and Kemp, 1998; Schot and Kanger, 2018). It is thus often argued that radical, transformative innovation emerges in niches, which are protected spaces where innovations can be nurtured outside the common selection environment (regime) (Smith and Raven, 2012; Verhees et al., 2015). A transition is seen as a multi-level outcome that puts existing regimes under pressure through niche innovation from the bottom-up, as well as landscape pressures from the top down. Landscape pressures include system-external developments, such as climate change, wars, pandemics or financial crises, which open up windows of opportunities for niches to break-through.

With regard to the role of innovation, on the one hand, innovation is studied in terms of technological niches, i.e., novel, yet unstable socio-technical configurations. The governance has thus focused on strategic niche management, which argues for the protection and nurturing of niches and addresses various aspects of upscaling, mainstreaming, translating and embedding (Hoogma et al., 2002; Von Wirth et al., 2019). On the other hand, there is a focus on the transformation of the entire socio-technical system, which then focuses also on questions of regime destabilization as essential for the break-through of niches. Innovation is seen as one of the most important drivers of societal change and at the heart of system transformation. As such, the expectation for innovation is considerably higher than in the previously described paradigms.

At the same time, the definition of innovation in this school of thought is not uniform. It ranges from a linear understanding of innovation as the exploitation of inventions, towards a broader understanding of innovation as the development of new socio-technical configurations. While the former has a focus on knowledge and R&D activities, the latter also pays attention to innovation in all other system elements, such as new business models, institutions, actors, practices, technologies, and other material infrastructure.

Schot and Steinmueller (2018) subscribe to and elaborate on the challenges formulated by Weber and Rohracher (2012): directionality, experimentation, coordination, reflexivity. Two issues surface as particularly important. Firstly, transformative innovation policy requires the involvement of a much broader set of actor groups, and, in particular, actors that innovation policy has traditionally not focused on, including niche actors, civil society organizations, philanthropic organizations, and users and society more broadly defined (Kemp et al., 2007; Kuhlmann and Rip, 2014). Such broad actor involvement places new challenges on governance. Kuhlmann and Rip (2018) describe this new form of governance as distributed and driven by institutional entrepreneurs (Battilana et al., 2009), which implies that governments need to find new ways of bringing together a variety of actors, nudge them to work towards sustainability transition, and build capabilities to evaluate the outcomes. The second aspect refers to the question of how to deal with the discontinuation of existing, unsustainable systems, often referred to as regime destabilization (Stegmaier et al., 2014; Turnheim and Geels, 2013). TIP encourages policy interventions that are targeting the de-institutionalization of existing structures in order for niche innovations to break-through. Scholars have, for instance, studied the role of phase-out policies in the energy sector (Kivimaa and Kern, 2016; Rogge and Johnstone, 2017) or exnovation in firms (Heyen et al., 2017).

Furthermore, TIP focuses on experimentation, reflexivity and evaluation as important cornerstones. Experiments are seen as 'actionable expressions of novel governance and socio-technical arrangements' (Sengers et al., 2021) that allow for the alignment and institutionalization of a new socio-technical system (Fuenfschilling et al., 2019). Experimentation has received attention in the area of sustainability transitions, in particular regarding climate and urban governance (Bulkeley and Castán Broto, 2013; Evans, 2016; Sengers et al., 2019; Turnheim et al., 2018). Reflexivity is another important aspect of TIP that is assumed to be essential to increase second order learning as well as contribute to a more formative evaluation approach (Haddad and Bergek, 2020; Weber and Rohracher, 2012). Scholars have argued that TIP necessitates a new way of assessment, such as formative evaluation rather than summative, and novel evaluation criteria that capture system change (Ghosh et al., 2021). Overall, it is argued that TIP " […] is not just a nice addition to current thinking about science, technology and innovation policy, it necessitates a rethinking of it" (Schot and Steinmueller, 2018, p. 1583).

3 Theoretical Implications of the Augmented Expectations

As discussed in section 2, the three perspectives to innovation policy differ in the intended policy outcomes. It is the shift in intended policy outcomes towards realizing system change, which is at the heart of the augmented expectations for transformative innovation policy. This shift in intended outcomes has important theoretical implications. In particular, system change is thought to constitute a wicked problem, and to require radical innovation. In contrast, in the context of linear or system innovation policy, the desired outcomes are not associated with wicked problems and promoting incremental innovation was common. In this section, we problematize this shift in intended policy outcomes in order to build the foundation for discussing the role of innovation policy for system change in Section 4.

3.1 Intended Policy Outcomes – From Innovation Towards System Change

The general understanding of innovation ranges from a rather narrow definition of applied scientific knowledge in the linear perspective, to the broader definition of new creations of economic or societal importance in the innovation systems perspective, and innovation as the development of new socio-technical configurations in the transformative innovation policy perspective. While linear and innovation systems policies predominantly consider innovation as a mean to stimulate economic growth and competitiveness, transformative innovation policy aims at system change. The latter entrusts innovation policy with a much larger role in society than it has been in the linear and innovation systems perspectives.

While there is a clear difference in the intended outcomes between the three policy perspectives, we argue that there has been an unhelpful and confusing conflation of terms, as illustrated with the notions of innovation and system innovation. While innovation is generally defined as the generation and diffusion of new products, processes, or business models, system innovation mostly refers to deep-structural changes in socio-technical systems – a concept used often in the transformative innovation policy literature. A clear distinction between innovation and system innovation is important because these two terms, albeit similar in wording, represent very different phenomena. System

innovation stands for system change, and to avoid confusion, we stick to the latter term. Keeping a clear distinction is necessary to study and understand the relationship between innovation and system change and thereby essential for deriving implications for innovation policy.

The justification for linear and innovation system policies has been that innovation generates largely desirable societal consequences, in particular via economic growth and increased competitiveness. However, while there is literature on the processes that lead to innovations (Bergek et al., 2008; Edquist, 2005; Hekkert et al., 2007), the exact mechanisms through which innovations translate into societal consequences have largely been ignored in the formulation and implementation of innovation policy and respective academic literature, implying a neglect of the societal consequences of innovation. Recently, work on responsible research and innovation has started to address this shortcoming (Owen et al., 2021, 2020). In contrast, transformative innovation policy aims to promote a change of socio-technical systems. This is why the literature on transformative innovation policy and sustainability transitions places a strong emphasis on how institutional complementarities (regimes) as well as material infrastructure create lock-ins. In this context, innovation is often equated with emerging niches, i.e. novel socio-technical configurations that, under the right conditions, can scale and replace existing, unsustainable regimes and thereby change socio-technical systems.

System change is thus a broader construct than innovation, including novel alignments between institutions, actors and material infrastructure. For instance, a transition to renewable energy does not only entail the invention of photovoltaic or wind turbines, but also the development of new laws, regulations and standards (e.g. feed-in tariffs, building codes), new professional education and reskilling (e.g. master programs in renewable energy), new market incentives (e.g. subsidies) as well as the de-legitimation and banning of existing energy technologies based on fossil fuels. This also means that innovation defined classically as the generation and diffusion of new products, processes, or business models is not seen as a sufficient condition for system change. Pushing this further, one could argue that innovation may not even be a necessary condition for system change. The latter may for instance be the case if the societal challenge to be addressed is largely social, such as poverty, or where the adequate solutions have already been tested and are readily available, and the problem is mainly centered on questions of diffusion of solutions.

Moreover, linear and systemic innovation policies can be distinguished in a similar way by their desired policy outcome. Strictly speaking, the prime focus of linear innovation policies is invention, largely ignoring the process of diffusion and commercialization, thus neglecting parts of the innovation process. In contrast, the focus of innovation system policies is innovation, i.e. creating the conditions for both the creation of new knowledge and the combination of knowledge in interactive learning processes between different types actors, and consequently the generation and diffusion of innovation. Therefore, and as commonly agreed, invention is neither a sufficient nor necessary condition for innovation. It is not a necessary condition because there are different types of innovations and not all require (technological) inventions.

These intended outcomes of each policy perspective are also reflected in the respective policy instruments. The arsenal of linear innovation policy consists mainly of direct support instruments (such as government R&D grants) as well as early mission-oriented programs (such as the Apollo mission). The innovation systems perspective adds an emphasis on developing linkages between actors and

shaping the overall institutional environment, as well as introducing demand-side policies to the mix. Transformative innovation policies, given their broader societal focus, introduce an emphasis on inclusive governance, regime destabilization, experimentation and reflexivity/learning. Overall, we can see that the scope of innovation policy has been continuously expanding, and, within the transformative perspective, increasingly aiming at system change.

3.2 System Change as Wicked Problem?

As discussed above, transformative innovation policy, including the new types of mission-oriented policies, aims at system change to address societal challenges, which are often characterized as wicked problems (Levin et al., 2012; Wanzenböck et al., 2020). Hence, a further development of innovation policy to meet the intended policy outcome of system change needs to pay due attention to the notion and characteristics of wicked problems.

The notion of "wicked problems" was introduced by Rittel and Webber (1973) against the background of planning problems in the 1970s. The authors argued that until then, planners had dealt with the "easy" problems, which could be addressed with technical/engineering solutions such as installing water and sewage systems, paving the roads, providing housing, and serving all communities with schools and hospitals. The remaining difficult problems – and the authors referred mainly to social problems such as inequality – are of a different nature that could not be solved with technical or engineering solutions. In fact, the authors argued that these difficult problems can never be conclusively solved, but in the best case continuously re-solved. For instance, there is no final solution for inequality per se, but any resolution will always entail a negotiation of interests and powers between groups and evolve over time (a similar argument was made by Nelson (1977) in "The Moon and the Ghetto"). This idea from the 70s clearly resonates with the current debate on societal challenges, in particular the claim that technological solutions alone will not suffice to address them.

Table 1. Features of wicked problems (Lazarus, 2009; Rittel and Webber, 1973)

Features of wicked problems
1 This problem is difficult to define
2 There is no way of knowing what an acceptable solution would be
3 Solutions may be evaluated more on normative than empirical criteria
4 There is no immediate or ultimate test for solutions to this problem
5 Solutions to this problem tend to have effects that may not be reversible or forgivable
6 This problem has no clear solution, and perhaps not even a set of possible solutions
7 This problem is unique
8 This problem might be the symptom of another problem
9 There are multiple explanations for the emergence of this problem
10 The planner (policymaker) has no right to be wrong
11 Time for addressing this problem is running it out
12 There is no central authority for addressing this problem
13 The same actors causing the problem seem to solve it
14 The future is discounted radically so that reaching agreements in the short term is valued too much by decision-makers

A second aspect in Rittel and Webber's work links surprisingly well to the contemporary discussion about transformative innovation policy, namely the focus on directionality (Weber and Rohracher, 2012). Rittel and Webber (1973) argue that the difficult planning problems essentially call for "[…] a clarification of purposes, for a redefinition of problems, for a re-ordering of priorities to match stated purposes, for the design of new kinds of goal-directed actions, […]" (p. 157). As we witness in relation to climate change, inequality, or poverty, the provision of directionality is deeply contested as conflicting interests of different groups in society clash (Wanzenböck et al., 2020). Climate change has even been defined as "super wicked problem" with the additional features that time is running out to address it; that the nations most capable of addressing climate change are producing most greenhouse gases and are less affected by the consequences of climate change; and that there is no authority or institutional framework of governance in place for tackling this challenge (Lazarus, 2009; Levin et al., 2012).

Even though the features of wicked-problems appear to resonate with in particular the challenge of climate change, critical voices argue that the notion of wicked-problems may have been stretched too far, and even if a problem is defined as wicked, this might not mean that solutions to it do not exist (Peters, 2017). For instance, poverty may be perceived as a wicked problem, but effective policies do exist. The Economist (13th February 2021) estimated that child poverty in the US could be cut by one third or one half through direct monthly payments per child as suggested by the Republican senator Romney and the White House respectively. Furthermore, Peters and Tarpey (2019) show that wickedness is more a matter of degree than a feature that can a priori be associated with a specific desired system change. In other words, it may be an empirical question whether a specific desired system change requires addressing a wicked problem, and whether the problem and/or solution space are ill-defined and contested (Wanzenböck et al., 2020).

3.3 System Change in Need of Radical Innovation?

The shift of the intended policy outcome to system change has come with the argument that radical innovations are necessary as drivers of system change while incremental innovations often hinder such change (Geels, 2002). The difference between incremental and radical innovations relates to the extent to which products, processes, or business models deviate from existing ones. Schumpeter (1911) foregrounded radical innovations where past experience could not inform the outcome of innovation, this means where technological and market uncertainty are high. Innovative entrepreneurs pursue such activities because they believe in a not yet realized opportunity (Shane and Venkataraman, 2000). An example is the generation and diffusion of personal computers, where there was little past experience to build on with regard to its potential success or failure. In contrast, incremental innovations are characterized by a low degree of uncertainty, where past experience can inform the expected outcome of an innovation process. An example would be the adoption of diesel particulate filter in cars, that represents a step forward in the vehicle's environmental performance, but not in the overall mobility experience for the user.

Transformative innovation policy aims at changing socio-technical systems from the current to a new configuration (i.e. transition), which implicitly invokes the idea of radical (disruptive) change, often in several socio-technical systems at once (deep transitions) (Schot and Kanger, 2018). In other words, it invokes the idea of breaking with existing ways of producing, distributing, and consuming basic

functions in society, such as, for instance, giving up the use of private cars as central component in the socio-technical system of personal mobility. This kind of system change is often related to radical innovations in the classical sense that break up the path-dependency of systems (Dosi, 1988; Winter and Nelson, 1982).

However, the relationship between radical innovations and system change is not entirely clear, especially not regarding the question of how many system elements need to radically change in order to achieve system change (Dolata, 2009). Can system change also be the result of incremental changes of many system elements building on each other that in their sum, at specific points in time, can be perceived as radical shifts, i.e. transitions? In relation to personal transport, this could be the replacement of the combustion engine with an electric one but continued use of private cars. Yet, such a seemingly small system change would require radical innovation in terms of, for instance, new engines, batteries, charging technologies, and consequently a major disruption of required competences and global production networks. This particular example of system change, would maintain the relevance of many institutions (e.g. traffic rules) and built infrastructures (e.g. roads). Therefore, as we will pick up in the next section, another open question in this context is whether addressing societal challenges necessarily requires disruptive system change.

4 On the Role of Innovation Policy for System Change

System change is qualitatively a very different intended policy outcome from promoting inventions or innovation for economic growth. Hence, it needs to be critically discussed what role innovation policy, which is made to promote innovation, can play for system change. Hence, in this section, we reflect upon the necessary conditions for system change and which approaches are available for innovation policy to contribute to system change.

Taking inspiration from literature in political science about how to address wicked problems (Cashore and Howlett, 2007; Levin et al., 2012) as well as on institutional literature on creeping change (Streeck and Thelen, 2005) we consider it relevant to conceptually differentiate between disruptive system change and progressive system change, which both aim at a transformation of existing systems. However, the paths to transformation are very different. Disruptive system change refers to a large initial change from existing socio-technical systems while progressive system change is characterized by many small changes which cumulate over time in new configurations. While the debate on transformation or transition of socio-technical systems invokes the idea of radical and disruptive change, cumulating smaller changes may be more powerful if these changes are self-reinforcing, lead to increasing returns, and positive feedback. Pursuing this argument, Levin et al. (2012) suggest using the mechanisms of path-dependency for the advantage of impactful policies.

Any policy that intends a disruptive system change will face contestation of many stakeholder groups, and the potential problems and solutions will be viewed differently. For instance, it would be highly contested whether the private car (and the abandoning of it) is the appropriate formulation of the problem and solution for the personal transport system. Hence, disruptive system change is a highly wicked problem. For such contexts, the new “experimental” innovation policy tools (including new types of mission-oriented policies) have been developed, which aim at developing new solutions in domains of high technological and market uncertainty (Robinson and Mazzucato, 2019; Sengers et al.,

2019). In contrast to traditional demand- or supply-side policies, experiments and missions integrate a variety of stakeholders in the process of trying out different ways of organizing or configuring the production, distribution, and consumption of societal functions. This allows to learn about the multiple perspectives on problems and solutions of different stakeholder groups and learn how different actors react to and relate in different configurations. The generation of "protected niches" in which experiments can be conducted is a new domain of innovation policy (Kemp et al., 1998).

Finding a way through an ill-defined problem-solution space through experimentation is in itself a very difficult process and not sufficient to realize disruptive system change. At least equally important are tough policies in relation to infrastructure and regulations. Disruptive system change calls for divestment in old infrastructure and investment in new infrastructure, as well as the destabilization of existing institutions and the establishment of new institutions (Kivimaa and Kern, 2016). Going back to the example of personal transport, and assuming (not very realistically) that actors settle on the idea that the use of private cars is the main problem, this would devalue existing road infrastructure and require new infrastructure investments (e.g. turning roads into pedestrian streets or greening them, while creating infrastructure for alternative forms of public transport). It would among other things render most traffic regulations useless and would require a complete rethinking of land-use planning. Hence, any potential solution in a perceived future without private cars triggers discontinuities in infrastructure and regulations.

This is in stark contrast to progressive system change. In this case, traditional supply-side or demand-side innovation policies may play an important role (for a comprehensive list on those tools see Edler and Fagerberg (2017). Continuing with the example of personal transport, instead of fundamentally questioning the workings of the existing socio-technical system, progressive system change focusses on several "lower" level problems such as electrifying cars, enhancing public transport, and changing land-use planning priorities – thus reducing environmental impact within the existing socio-technical system. Each of these lower level problems can be addressed with a mix of supply- and demand-side policies. Taking the example of electrifying cars, a number of policy tools are essential, not the least to reduce market uncertainty by setting strict regulations on carbon emissions of cars and clear political goals of phasing out combustion engines. At the same time, supply-side policy tools help reducing technological uncertainties with for instance directed R&D support to firms, universities, and research organizations.

In addition, progressive system change differs in the type of infrastructural and institutional change required as compared to radical change. Progressive system change allows to reuse existing infrastructure to a much larger extent, even though requiring adaptations. Continuing with the example of personal transport, roads would remain a relevant infrastructure but would need to be complimented with charging stations or similar infrastructure relevant for electric vehicles. At the institutional level, regulatory change creating market certainty about the electrification of transport and standards facilitating the diffusion of new technologies are important. However, the more informal institutions questioning for instance the private car as status symbol, do not need to be questioned in principle. It is important to note that the interplay between changes in different system components may have a reinforcing character. For instance, if changes in land-use planning, expanded public transport, and changes in the organization of work make private cars less relevant, it may erode its status and consequently the demand for it. Yet, how the various changes in the existing socio-

technical system play together to generate new properties at the level of the socio-technical system must be seen as an emergent and open process. This means it cannot be predicted even if the direct results of the multiple single changes of various elements of the socio-technical system would be known in advance.

Taking this discussion further, while system change – meaning the shift from one socio-technical system to another – may be a wicked problem, addressing lower level problems relating to the elements of existing socio-technical systems are typically not wicked. Focusing on addressing lower level problems is in line with the idea of promoting progressive system change. However, addressing lower level problems does not necessarily imply that the socio-technical systems remains locked-in, or in other words, cannot shift to another state where, for instance, carbon-neutrality is achieved. This is because changes at lower levels (i.e. various components of the socio-technical system) may combine in ways that induce a shift of socio-technical systems in the longer-term. In line with this Levin et al. (2012) argue that "greater attention should be placed on what are often much easier to change lower order policy levels in order to assess whether there are opportunities for initiating policy change capable of unlocking progressive incremental trajectories that ratchet up over time to create more meaningful impacts."

In reality, however, it can neither be imagined that a system transforms (e.g. to carbon neutrality) without some more disruptive changes, nor that a system transforms without continuity of certain system elements. System transformation is a messy process where various systems interact in intricate ways, which cannot be foreseen and planned. Hence, this foregrounds the emerging character of system change and provides an argument for a policy that allows for and seeks interventions in a variety of system elements and at different levels at the same time, which would also enable the development of local solutions. The most important implication for innovation policy is the uncertainty and unpredictability of such a process. This means that the possibility to plan and coordinate system change is severely limited. In contrast, it suggests that innovation policy actors need to develop their reflective capacity and adaptability – i.e. to monitor how system change unfolds, assess the risks and opportunities, and be quickly able to adapt their strategies when setting directionality.

A tangible example are electric scooters. This is an innovation, which may hold promise to contribute to system transformation, for instance if people switch from cars to electric scooters. However, if electric scooters instead are used by people who otherwise would have walked, and make it more difficult to navigate a town by foot or cycle, then this innovation may have unintended and unwanted consequences. This is a simple example. More complex would be the discussion about smart mobility and self-driving vehicles. On the one hand, autonomous driving may facilitate the use of shared vehicles, thereby reduce consumption of material resources and required land-use for transport. On the other hand, self-driving vehicles may make private cars even more attractive, thereby working against more resource efficient mobility. The outcomes cannot be foreseen but need to be monitored regularly and policies adapted depending on how a system emerges. In such a process, the above discussion about progressive system change provides a useful guide. Do we see that the policy interventions promote progressive system change, creating momentum for system transformation, or do the interventions (have a high risk to) create systemic lock-ins in unsustainable patterns of consumption, distribution, and production?

We would thus argue that the reflexivity failure is the most important and intricate of the transformative failures identified by Weber and Rohracher (2012). This is because directionality and demand articulation can be addressed by using existing supply- and demand-side innovation policy tools (Edler and Fagerberg, 2017), or adapting them accordingly. An important purpose of regulations is to provide directionality. Economic and fiscal incentives such as R&D subsidies can be linked to a conditionality and ex-ante evaluation / assessment about the potential societal impact. Demand can be articulated by, for instance, functional procurement policies (Edquist and Zabala-Iturriagagoitia, 2012). An example of the search for increased directionality can be found in mission-oriented innovation policy (Foray et al., 2012; Mazzucato, 2018). With the missions approach, governments have embarked on a quest to respond to societal challenges, often by deploying traditional innovation policy instruments under broader mission umbrellas (Larrue, 2021), thus adding the necessary directionality to the existing innovation policy. The innovation policy toolkit would thus nominally be the same when it comes to transformations, but an effort would have to be made to guide the efforts towards certain politically agreed societal challenges. The main problem is thus not how to implement directionality through innovation policy but to know which direction to give, and the latter question can only be answered if policy makers develop their reflexivity about system emergence. As the debate on just transitions highlight, such reflexivity also needs to be attentive to democratic legitimacy (Jasanoff, 2018; Swilling, 2020). Our discussion thus foregrounds reflexivity and adaptability before planning and coordination. High-level strategic policy objectives are important (e.g. in relation to decarbonization) and missions may be one way to do so. However, the emergent nature of system change makes a "tight" coordination undesirable, and highlights the need for alternative solutions in order to provide time to generate valuable data on the impact and consequences of innovations and system changes. More important is a dialogue between levels of governance and different sectors to facilitate feedback loops and learning. That way all levels of government can quickly adapt, and navigate system emergence towards progressive (and maybe disruptive) change and away from undesirable lock-ins.

5 Conclusions

In this paper, we scrutinized the promises and limitations of innovation policy to address societal challenges. To this end, we studied the foundations of the three most prominent innovation policy perspectives, namely linear innovation policy, system innovation policy and transformative innovation policy. We examined their underlying definitions of innovation and innovation policy, the role innovation is assumed to play for societal development, and what kind of policy instruments are suggested to tackle societal challenges.

Based on this analysis, we argued first that the shift from innovation to system innovation as the targeted policy outcome is the main underlying reason for the augmented expectations for innovation policy. Yet, insufficient attention is paid to the very different meaning of the terms innovation and system innovation, and their conflation causes fundamental problems. While the former refers to the generation and diffusion of new products, services and business models, the latter refers to broader system change that may or may not entail innovation in the sense of the former definition. We argue that innovation and system innovation are two different phenomena that can, but do not have to be interdependent. Hence, policy that targets innovation is naturally different from policy that targets system change.

Second, we identify that the literature on transformative innovation policy has rediscovered the notion of wicked-problems. In fact, system change to address societal challenges is often seen as wicked-problems. We have thus elaborated on this notion and its defining features, which led us to emphasize its contested character. This means that different groups in society typically have very different views about the problem formulation and what acceptable solutions are. Further, the problem of governance in so-called super-wicked problems was emphasized. Yet, we also discussed critical voices suggesting that not all system changes for societal challenges entail wicked-problems.

Third, the three innovation policy approaches differ in their understanding and treatment of incremental versus radical innovation. On the one hand, the discussion of incremental versus radical innovation in the context of the generation and diffusion of new products, services and business models often refers to different degrees of technological and market uncertainty and whether past experiences can inform future actions. System change (system innovation), on the other hand, is almost always assumed to be radical and disruptive in the sense of necessitating a transformation, if not replacement, of the whole underlying socio-technical system. However, we also argued that the literature is not fully clear if the "system" needs a radical and disruptive change or whether this refers to system elements, and if the latter to which system elements.

Taking inspiration from literature about wicked-problems in political sciences, we then proposed to conceptually distinguish between disruptive and progressive system change, as summarized in Table 2. Policy that targets disruptive system change deals with high-level problems, which are the true wicked problems where neither the problem nor the solution space are defined. This makes it difficult to employ the traditional innovation policy toolbox. For instance, it would not be clear what actions or behavior to incentivize or to discourage, or to regulate. Experimental innovation policies are applied in order to engage a variety of stakeholders with the aim to clarify and often negotiate which problem formulation and potential solutions are acceptable. In addition, we show that disruptive system change typically require a discontinuation and replacement of existing infrastructure and institutions.

Medium-level problems are more tangible and less wicked. Addressing medium-level problems makes progressive system change possible, which is about transforming different system elements that in the aggregate can reinforce each other over time to generate new properties at the system level, and eventually result in system change. We show that mission-oriented innovation policies and the traditional innovation policy toolbox has potential to contribute to progressive system change. Clearly, the traditional innovation policy toolbox need to be adapted to counter transformation failures related to directionality, demand articulation, reflexivity and coordination (Weber and Rohracher, 2012). We argue that many traditional innovation policy toolbox can be used to exercise directionality or promote demand articulation. More importantly, however, we discuss why the emergent character of progressive system change puts particular emphasis on reflexivity and adaptability of innovation policy. Further, we show that innovation policy needs to be complemented with interventions transforming (or adapting) existing infrastructure and institutions.

Table 2. Disruptive system change vs progressive system change

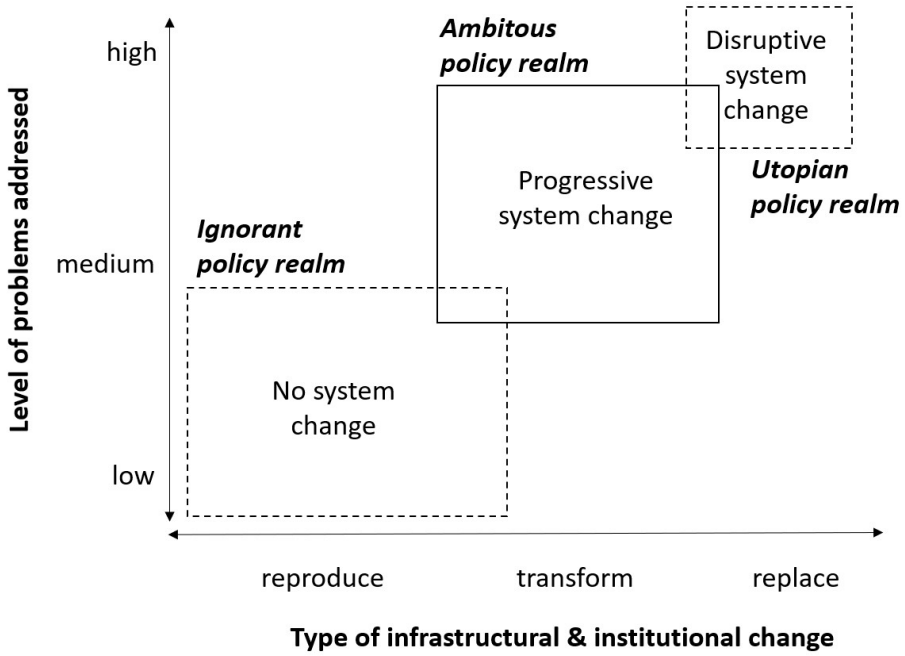
Type of system change	Level of problems addressed	Type of (innovation) policy	Type of infrastructural and institutional change
Disruptive system change	High-level problems (true wicked problems)	Experimental innovation policies	Replace (discontinue) existing infrastructure and institutions
Progressive system change	Medium-level problems	Mission-oriented innovation policies Traditional innovation policy toolbox adapted to counter transformation failures Reflexivity and adaptability of innovation policy essential	Transform (adapt) existing infrastructure and institutions
System maintenance	Low-level problems	Traditional innovation policy toolbox supporting incremental innovation in existing socio-technical systems.	Maintenance of existing infrastructure and institutions

Finally, we also discussed the risk of addressing low-level problems, which lead to system maintenance, the stabilization and reproduction of the existing system. It is important to note further, that traditional innovation policy tools may also promote system maintenance if targeted at incremental innovation defending existing socio-technical systems. If systems don't change, existing infrastructure and institutions are maintained.

To be sure, policy makers are confronted with a messy reality where system boundaries are difficult to define and various systems (e.g. transport, energy, food) overlap. Furthermore, in such a messy reality, system change could neither be imagined without radical change of some system elements, nor without continuation of some other system elements. It is thus necessary for policy makers to identify an ambitious but workable policy realm to address societal challenges. This is summarized in Figure 1. An ambitious policy realm consists of targeting progressive system change by addressing medium and sometimes also higher-level problems with the adequate innovation policy instruments as discussed above, and combine this with policies to transform (and sometimes replace) existing infrastructures and institutions. Progressive system change is ambitious and may include radical innovations, for instance for energy storage solutions, which contribute to changing energy systems but are still complementary to other existing system elements. Progressive system change requires reflexivity and political will because it entails continuously adapting policies and incentive structures, including withdrawing support from some (innovation) policies that reproduce existing structures, or that turn out not to produce the desired system outcomes.

In contrast, we would argue that a focus on disruptive system change is a Utopian policy realm because of the contestations it would trigger. Experimental innovation policy may be employed to address the contestations but will most likely end up with a resolution that entails elements of continuity and change, hopefully contributing to progressive system change (and not reproduction of the existing system). However, in policy practice stakeholders may also avoid contestations and resolving conflicts, and in consequence not exercise the desired directionality to address societal challenges (Grillitsch et al., 2019). Experiments may also be locally successful but scaling them can be a challenge (Bulkeley et al., 2019). We consider this important because foregrounding disruptive system change, investing too much resources in "experimenting" and unrealistic policy goals at the expense of more hands-on and tangible interventions that lead to many smaller but cumulative and self-reinforcing changes over time, cannot be the right approach if the arguments advanced in this paper hold. On the other end of the spectrum, policies targeting low-level problems leading to no system change and reproduction of institutions and infrastructure are simply ignorant to the existential societal challenges we face and need thus be disregarded as well.

Figure 1. Dimensions of change



Overall, our discussion has shown that innovation policy alone is not sufficient and, in some cases, possibly even not necessary to address societal challenges. A major reliance on innovation policy only would be a fatal error. However, venturing out into policy spheres that are not related to innovation, as is often done when referring to system innovation, undermines the potential of innovation policy to become more transformative in its own domain. Many innovation policy tools can be tweaked to respond to transformative failures better. However, how the necessary reflexivity and adaptability of innovation policy can be achieved is a key question, especially from a theoretical perspective where innovation in various system elements can lead to new system properties that cannot be anticipated (i.e. in the case of progressive system change). Also, tweaking many elements of the system (following the progressive idea) may suddenly lead to discontinuities that need to be managed. Questions of reflexivity and adaptability of policy interventions are thus taking center stage in policy making under uncertainty, within the innovation policy domain and beyond.

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