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The Politics of Selection: Towards a Transformative Model of Environmental Innovation

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Received: 8 November 2018; Accepted: 15 January 2019; Published: 18 January 2019

Abstract: As a purposive sustainability transition requires environmental innovation and innovation policy, we discuss potentials and limitations of three dominant strands of literature in this field, namely the multi-level perspective on socio-technical transitions (MLP), the innovation systems approach (IS), and the long-wave theory of techno-economic paradigm shifts (LWT). All three are epistemologically rooted in an evolutionary understanding of socio-technical change. While these approaches are appropriate to understand market-driven processes of change, they may be deficient as analytical tools for exploring and designing processes of purposive societal transformation. In particular, we argue that the evolutionary mechanism of selection is the key to introducing the strong directionality required for purposive transformative change. In all three innovation theories, we find that the prime selection environment is constituted by the market and, thus, normative societal goals like sustainability are sidelined. Consequently, selection is depoliticised and neither strong directionality nor incumbent regime destabilisation are societally steered. Finally, we offer an analytical framework that builds upon a more political conception of selection and retention and calls for new political institutions to make normatively guided selections. Institutions for transformative innovation need to improve the capacities of complex societies to make binding decisions in politically contested fields.

Keywords: environmental innovation; sustainability transition; transformation; evolutionary economics; multi-level perspective; innovation systems; long-wave theory; agency; decision-making; institutions

1. Introduction

The world is in the process of a two-fold 'socio-ecological transition' [1,2]. On the one hand, large parts of the world, including the 'emerging economies', are enmeshed in a transition from an agrarian, biomass-based economy to an industrial, fossil-energy-driven one. On the other hand, there are increasing global efforts to initiate a so-called 'sustainability transition' [3–5] away from a fossil-energy based economy to a post-fossil, sustainable one. While the industrial transition is by far the dominant phenomenon to date [2], there are signs that the per-capita energy and resource use has started to level off in the most advanced industrial countries [6]. There is a clear danger, however, that if the societal project of a transition to sustainability fails, there will be another type of transition: one that results from a combination of resource depletion and the violation of vital biophysical boundaries and that may end in socio-economic collapse [7–9].

Innovation policy has played an important role in both the on-going industrial transition and the incipient sustainability transition. However, while the industrial transition is driven by the inherent

dynamics of socio-technical evolution in a globalising world economy and by the universal quest for economic growth and material prosperity, the incipient *sustainability transition* is driven by *normatively* and *scientifically* defined goals that are, to some extent, countervailing these dynamics. Innovation has traditionally been at the service of the project of economic expansion, thereby contributing "massively to the current resource-intensive, wasteful and fossil fuel-based paradigm of mass production and mass consumption" [10], but has now to be put at the service of a transformation toward sustainability [11,12]. Innovation policy thus needs to become instrumental to transformation policy [10]. The *normative* nature of the sustainability transition, however, makes it an irreducibly *political* project, whose goals and objectives will always remain contested as they challenge vested interests, established values and deep-rooted social practices [13]. Until today, "transition and innovation policies [have] only [been] aligned when they stimulate innovations that contribute to both economic growth and sustainable development", as Alkemade et al. [11] put it. But as long as further growth continues to stimulate further resource consumption and as long as the leakage and rebound effects inherent to efficiency-driven innovations remain unresolved, this might not be good enough [14,15]. In this paper, therefore, we undertake a re-examination of dominant conceptions of environmental innovation with a view to their capacities to propel a comprehensive sustainability transition. We are particularly interested to find out if theories of innovation and socio-technical change in the environmental domain are adequately addressing the *directionality* of change required for a purposive societal transition [12]. In any truly transformative model of innovation theory and policy, directionality expresses the fact that the socially or politically willed direction of change might differ significantly from the patterns of change that typically drive innovation processes. Thus, the crucial question a transformative model of innovation needs to answer is how such externally (as in: extra-economically) defined directionality can be implemented and secured against the dominant dynamics of socio-technical progress in case both turn out to diverge significantly. More concretely, how can a purposively defined transformative trajectory be empowered and retained, even if the unsustainable alternatives were to promise more growth, higher consumer utility and higher profits?

In addition, we argue that a transformative theory of innovation needs to be able to address the problem of incumbent regime *destabilisation* [16] and thus of *creative destruction* [17] in a proactive, effective and purposive manner. Put another way, a transformative model of innovation fit for the purpose of a time-bound and radical transformation of industrial society toward sustainability may not content itself with the innocent role of fostering novelty, diversity and market choice; it will most likely have to be of a more determined, conflictive and 'creatively destructive' nature than its growth-oriented predecessors.

Theories of innovation (including the three dominant strands we analyse in this article) typically rely on evolutionary conceptions of socio-technical change. In evolutionary economic theory, change is emerging as a pattern of interactions between processes of variation, selection and retention of novel traits. While innovation is frequently reduced to its function of generating 'diversity' (variation), the crucial functions of selection and retention in turning diversity into purposive directional change are frequently undertheorised or left to the 'micro-processes' of individual choice which are conceptualised as aggregating into 'meso-trajectories' of change [18,19]. While convincing as descriptive-analytical accounts of socio-technical change in a market-mediated society under conditions of universal economic expansion, these evolutionary models, we argue, are lacking the conceptual instruments to capture fully the *political* nature of directionality and thus the *political* dimension of the selection and retention functions, in particular. In analogy to its epistemic roots in biology, socio-technical evolution is frequently portrayed as a *natural* and *apolitical* process that can be steered only by influencing the 'selection environment' within which populations of consumers and entrepreneurs make their respective choices. The idea that variation, selection and retention all can be (and usually are) subject to political (that is, binding collective) decision-making and will-formation has not yet been sufficiently applied to these theories of change. We argue that a theory of transformative innovation has analytically to embrace the political dimension of selection as well as of retention and variation and propose

institutional and procedural answers to the crucial question of how to implement transformative directionality, regime destabilisation and creative destruction.

Against this backdrop, we discuss the contributions of three influential strands of literature in the field of environmental innovation and transition studies. These are the multi-level perspective on socio-technical transitions (MLP), the innovation systems approach (IS), and the long-wave theory of techno-economic paradigm shifts (LWT). We then propose an analytical framework, based on the distinction of so-called 'agentic operators', which proposes a more political conception of selection and retention. We conclude with some concrete proposals for the conception of transformative innovation policy and with suggestions for further research.

2. The Multi-Level Perspective (MLP)

In recent years, the multi-level perspective on socio-technical transitions has become perhaps the most influential theoretical framework in the field of environmental innovation [20]. Combining concepts from evolutionary economics, science and technology studies, structuration theory and neo-institutional theory, the MLP builds on an analytical distinction of niches, regimes and landscapes as functionally distinct but interrelated levels that shape the process of socio-technical transitions. Niches are the locus of radical innovation; they are 'protected spaces' such as "R&D (research and development) laboratories, subsidised demonstration projects or small market niches where users have special demands and are willing to support emerging innovations". In this perspective, "niches are crucial for transitions, because they provide the seeds for systemic change" [21].

Such systemic change can only occur, however, when and if radical innovations manage to pervade and restructure the level of the socio-technical regime. Since transitions are defined in the literature as shifts from one regime to another, this is the crucial analytical level for transition research [21]. The socio-technical regime forms the 'deep structure' that accounts for the stability of an existing socio-technical system. It "refers to the semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems" [21], such as "cognitive routines and shared beliefs, capabilities and competences, lifestyles and user practices, favourable institutional arrangements and regulations, and legally binding contracts" [21].The rules of a regime account for the stability and lock-in of a concrete socio-technical system [22].

The landscape level, finally, "highlights not only the technical and material backdrop that sustains society, but also includes demographic trends, political ideologies, societal values, and macro-economic patterns" [22]. What defines the landscape level analytically is that it presents "an external context that actors at niche and regime levels cannot influence in the short run" [22].

A typical pattern of a socio-technical regime transition would be that (a) niche-innovations build up internal momentum, (b) changes at the landscape level create pressures on the regime, and (c) destabilisation of the regime creates windows of opportunity for niche innovations [22]. Historical examples of radical innovations like the automobile show an impressive journey from their start in a niche, through the domination of entire regimes to their structuring of the global socio-technical landscape.

The main transformative task from the multi-level perspective is to *manage* the all-important interaction between niches and regimes in a purposive and goal-oriented way. To support a sustainability transition means to help radical environmental innovations get off the ground in niches and pervade the socio-technical regimes. In order to do so these innovations must break established rules and structures in the regimes, which lock them into their current state. The purposive management of the interaction of niches and regimes has become a central concern within the MLP literature, and led to the development of specific sub-strands like transition management (TM) [23] and strategic niche management (SNM) [24].

Drawing on evolutionary economics, the MLP and its transition management variants apply the Darwinian concepts of variation, selection and retention to the socio-technical evolution of modern societies. Regimes are conceived both as *retention* structures and *selection* environments for innovations

(*variation*) [22,25]. In their capacity as selection environments for innovative variants regimes comprise a number of structural features that work as selection mechanisms, including market mechanisms and dominant user practices, established industry structures, dominant technologies and infrastructures, and public policies [25]. The aim of transition (and strategic niche) management now is to introduce a certain measure of agency into these processes. Whereas variation in capitalist market environments is usually driven by the profit motive (i.e., by firms' interest to survive in the market and, ideally, to grow; see [26]), the aim is now to introduce 'directed variation' that is not only driven by market interests but also by other (sustainability-related and thus normative) intentions [22].

What the evolutionary perspective tends to neglect, however, is the fact that the evolutionary dynamics of modern industrialism, which serve as the epistemological foundation of the MLP, could only unfold in an environment that was characterised by an expansive (fossil) energy system. The evolution of modern economy has been based on the availability of ever increasing quantities of cheap, concentrated and abundant energy [27–29]. The selection mechanisms at work were and are geared towards further expansion and growth of the system. When left to the evolutionary dynamics that were unleashed some 250 years ago, it appears likely that the system will use up all the available energy it can find until it runs into the landscape pressures of resource shortages, price increases and severe environmental constraints. The MLP and its variants aim at overcoming the evolutionary selection trap either through protecting and nurturing niches for sustainable innovations (SNM) [25] or through designing complex governance models that try to influence both variation and selection (TM) [30]. Both strategies tend to naturalise evolutionary selection pressures, however, by taking markets as given selection environments. Geels [31] argues that "most transition-scholars focus on 'green' niche-innovations, they pay less attention to existing regimes and incumbent actors, or conceptualize regimes as monolithic 'barriers to be overcome', which runs counter to the initial MLP-formulations and the emphasis on multi-level alignments". A literature review covering 386 journal articles concludes that a reason for new ideas not diffusing rapidly through companies may be due to "overarching structures of markets, patterns of final consumer demand, institutional and regulatory systems and inadequate infrastructures for change" [32]. This suggests that—despite its focus on governing the interface between niches and regime—the MLP literature tends to regard the selection mechanisms as naturally given, unquestionable and subject only to modification and management. Thus, TM, for example, "understands the relation transition initiatives adopt towards existing regimes not in political, but in market terms" [33]. According to Kemp and Loorbach [34] TM is about 'context control', so as "to orient market dynamics towards societal goals". While this may involve regulation and economic instruments, change itself emerges in an evolutionary manner as the aggregate of consumer choices. In that way, Kenis et al. [33] admonish, "transitions stay locked in a liberal market model that does not acknowledge the need of its own transition". In a word, MLP scholars try to insert some directionality into the governance of selection mechanisms they consider to be naturally given, instead of challenging the very nature of the selection mechanisms themselves. Recent attempts to unravel the political in MLP-based transition literature [35] tend to overstate the complexity of political processes involved when trying to give directionality to markets, thereby creating an endless field of future research that allows the more pressing task of designing transition mechanisms beyond the market to be evaded. We argue instead that the evolutionary selection trap may be effectively overcome only through the purposive construction of selection mechanisms that negotiate and ultimately express societal goals. It might, thus, be more important to focus on innovating the selection mechanisms of industrial societies and to equip them with purposefully designed (and democratically controlled) selection criteria than to focus on getting sustainable innovations selected by *unsustainable selection environments*.

A managerial approach toward the relationship between niches and the regime on the basis of market mechanisms also raises questions about the power of the niches to ever escape the normative force of the regime. As Bulkeley et al. [36] aptly put it, the "key role ascribed to government actors in creating 'protected' spaces for niche development [also] raises questions as to whether niches are established in order to maintain regimes rather than as a means of fostering change". As long as niches

are at the mercy of the regime to protect their space from the forces of the market until they are ready to compete, they remain subjected to the dominant logic of the regime and the market, which defines what successful competition means.

Thus, we suggest focusing on 'selection' instead of 'variation' and on regimes instead of niches. This is not because variation or niches are unimportant, but because the limiting factor is the purposive selection, upscaling and mainstreaming of innovations—if necessary against the regime—in order to transform the regime. Niches may be nested within regimes, but transformative innovation requires acknowledgement that their relationship may (or perhaps even must) at some point become antagonistic and thus requires institutions that are not managerial but political.

3. Innovation Systems

Another influential strand of innovation research is the innovation system (IS) approach. Rooted in evolutionary economic theorizing, it was developed as a policy concept in the mid-1980s [37–39]. In contradistinction to the MLP, the IS approach does not focus on the interaction between different levels of socio-technical emergence, but on the interaction of actors, networks and institutions in steering and influencing innovation dynamics. Its original aim was to make national economies more competitive and resilient under conditions of increasing global competition and receding growth rates after the oil crises of the 1970s [10]. According to Jacobsson and Bergek [40], innovation systems are composed of a set of structural elements: actors in the whole supply chain, networks, institutions, and, in some approaches, technology. While actors can be individuals or organisations, institutions are conceived along the lines of neo-institutional theory as formal and informal rules, "comprising laws and regulations, socio-cultural as well as technical norms, shared expectations, etc." [41]. Over the years, different types of innovation systems were analytically distinguished and conceptualised, including national innovation systems (NIS), sectoral innovation systems (SIS), regional innovation systems (RIS) and technological innovation systems (TIS).

With respect to sustainability transitions, the most productive approach within the innovation systems literature so far has been the TIS approach, which focuses on the development and diffusion of *specific* technologies, rather than on the general conditions of innovation in nations, regions or industry sectors. The purpose of TIS analysis is to identify possible system weaknesses that often result from the misalignment of system components in the sense that certain structures of the system hinder actors at cooperating or that the institutional preconditions for entrepreneurial experimentation are lacking. Institutional frame conditions such as funding schemes or research frameworks heavily influence the direction of search for new technological solutions and can potentially lead a TIS into a dead end. Similarly, there is a range of institutional and organisational preconditions for successful (human and financial) resource mobilisation and market formation. In the absence of a specific regulatory framework, for example, a new technology will have severe difficulties developing a market or attracting capital. In addition, a range of institutional conditions has to be met in order for a new technology to gain the political and cultural legitimacy to be diffused successfully [40].

In sum, the IS approach looks at the actors and institutions of specific innovation systems with the goal of identifying points of policy intervention that would help enhance the overall performance of the system or stimulate certain types of innovation. The focus of the IS approach is thus on the politics (the socio-institutional setting) of innovation rather than on the economics of innovation in a strict sense. This makes it an interesting approach in terms of addressing the purposive, normative and goal-oriented nature of a sustainability transition. Since the prospect of such a transition is widely believed to depend on the development, diffusion and comprehensive use of radical environmental innovations, the IS approach can help identify the points of intervention necessary to stimulate and support the success of such technologies. A clear focus in this literature is on the role the state plays in the creation and transfer of knowledge within innovation systems [42,43]. The assumption is that knowledge does not build up linearly but has to be mediated between different actors and organisations in order to become productive in an entrepreneurial way. Particular importance is attributed to the

role of state-funded research and universities in connection with private R&D activities, implying that "universities should become more entrepreneurial, fostering new company formation through spin-offs and licensing technology produced through university research" [10]. Recently, Mariana Mazzucato has emphasised the role states have (and have always had) in providing the direction towards "new 'techno-economic paradigms', which do not come about spontaneously out of market forces"[44]. Past socio-technical revolutions were decisively enabled and shaped by direct investments and funding decisions of states, who took on the role of venture capitalists [45]. However, the approach arguably suffers from constraints similar to those of the MLP as it grounds its ontology in an evolutionary process that it assumes as 'given'. Despite its acknowledgement of the state's role in "shaping and creating markets" [44], it considers market diffusion as the natural goal and (venture) capital attraction as the natural condition of innovation [44,45]. For the IS approach, "technological change and other kinds of innovations are the most important sources of productivity growth and increased material welfare" [46]. That way, fostering innovation appears as a naturally beneficial goal. In subjecting its concept of social utility to market forces, however, the IS literature risks paying insufficient attention to the question if and how selection can be controlled by societal goals other than productivity growth and material welfare. Put differently, the state in IS may be instrumental in strategically creating the conditions for new markets (and thus technologies) to emerge and, therefore, has the power to insert a certain measure of directionality into the innovation process (like promoting energy efficiency or raising the prices of fossil energy), but success or failure of the new technologies are decided under the 'normal' conditions of market take-up by consuming individuals and other market participants. As in past socio-technical revolutions, the strategically supported direction of innovation has to offer higher (or new) consumer utility, higher profits and new growth opportunities to prevail in the market, which remains the ultimate selection environment. To the extent that a sustainability transition requires the primacy of societal goals that might be incompatible with the above naturalised 'selectors' of the market, however, the IS approach in its current state may be ill equipped to lead societies beyond the established trajectory of socio-technological evolution.

4. Long Wave Theory—A Sustainable 6th Kondratiev?

The theory of long waves or techno-economic paradigms (TEPs) is the third approach to innovation thinking we want to discuss here. It combines the theory of long waves of economic development put forward most prominently by Nikolai Kondratiev (1935) with the evolutionary economic theory of Joseph Schumpeter that posits radical technological innovation as the "single root cause of the cyclical behaviour of the capitalist economy" [26]. Thus, Kondratiev waves are conceptualised as a succession of TEPs, each based on a decisive technological innovation (like the steam engine, the automobile or microelectronics), a core input (e.g., coal, oil or silicon microchips) and a carrier branch that drives the development (like railways, automobiles or the computer industry). Five such long waves or TEPs have shaped capitalist development since the Industrial Revolution at the end of the 18th century. The first was based on the water-powered mechanisation of industry and on the iron industry and started in the 1770s. The second was relying on the steam-powered mechanisation of industry and transport, dating back to the 1830s. The third was based on the electrification of industry, transport and the home and started in the 1870s. The fourth TEP was constituted by the motorisation of society, with the key innovation being Ford's Model-T automobile from 1914. The fifth and current TEP, finally, is based on microelectronics and started in the 1970s [26,47].

The succession of TEPs transforms societies economically and technologically in that it leads to extended phases of economic growth but also to socio-economic crises of 'creative destruction'. Typically, the new wave emerges out of the crisis of the old: as profit rates decline in the application of the incumbent paradigm, more and more 'idle' capital is invested in new technologies that promise greater potential for future profits. In socio-economic terms, however, the greatest disruptions occur when a new TEP is in its explosive growth phase competing fiercely with the established paradigm. It is the phase where investment bubbles in the new TEP occur, leading to great financial crises, and

where societies have to adapt institutionally and organisationally to the new paradigm (reacting to new forms of employment, new industries, the destruction of old industries and infrastructures and concomitant political changes). After this turbulent phase, the new TEP will continue to grow, promising a short period of sustained growth that Perez calls the 'Golden Age' of a TEP [48].

The study of TEPs is interesting for scholars of socio-ecological transitions for several reasons: Firstly, if the theory is a valid interpretation of capitalist development, it offers opportunities for ex-ante analyses of long-term socio-technical change in that "the recurring features of Kondratiev waves can be used to extrapolate forward to possible future waves" [49]. An interesting question, from a SET perspective is, then, which new technologies might qualify for constituting the next TEP and what contribution to a sustainability transition they could offer. Secondly, if a transition towards sustainability is our normative goal, the role of purposive agency in steering a TEP or in deciding which technology will dominate the next half century or so is decisive: can long waves be influenced or even purposively steered? Or are modern societies exposed to an evolutionary dynamic that is, more or less, beyond their control? A third issue regards the energetic basis of the long waves and the question whether a 'post-fossil' energy regime could sustain a sixth wave of capitalist development at all [50].

With regard to the forecasting of the next long wave, most literature regards biotechnology and nanotechnology to be the 'hottest' candidates for the role of key technologies and sees further potential in the development of information technologies [51–53]. To what extent these technologies have the potential to carry the burden of a sustainability transition is, for obvious reasons, difficult to establish. However, the more important question might be whether a future low-carbon Kondratiev wave is a plausible scenario at all. While Kondratiev waves or TEPs represent cyclical patterns of innovation, economic growth and socio-economic crisis, the historical metabolic profile of the five historic waves so far shows the pattern of an upwards spiral. Thus, these waves have shown cumulative metabolic rates, which means that each wave added further energy and material consumption to the previous one. As Köhler points out, "the first four waves were based around intensified use of energy resources, which increased pollution through new industrial activity" [49]. Similarly, Pearson and Foxon ([54] p. 125) point to the fact that previous industrial revolutions were "*high carbon* industrial revolutions: [. . .] their success was built on the exploitation, largely unconstrained by environmental or other regulatory concerns, of fossil fuel stocks that freed the economy from constraints it would otherwise have faced". Two important questions follow from these observations:

First, can a new TEP be envisaged that de-carbonises (by virtue of its technology-inherent properties) not only the new segment of growth industries that it adds to the inherited structure but the *entire* economy? The energy consumption in the Fifth Kondratiev, at least, does not suggest as much, since all it has achieved so far in this respect is a stabilisation but not an effective reduction in per capita energy consumption [6]. Related to this, can such a new, sustainable TEP be expected to not only decarbonise the legacy of its predecessors but also *add* a further wave of capitalist *growth and expansion*? It is of course difficult to make predictions about these questions but with the metabolic profiles of the hitherto Kondratievs in mind, which were all based mainly on cheap fossil energy, it is difficult to imagine that any technological innovation within reach today could help decarbonise the entire economy *and* add further growth to the system [50].

These considerations are important when contemplating the possibility of a *low-carbon industrial revolution*, as would be necessary for a sustainable next Kondratiev wave. As Pearson and Foxon point out, such a prospect faces a range of serious challenges [54]. Firstly, while the low-carbon technologies within reach today are good at helping decarbonise the existing economy in that they substitute 'green' alternatives for unsustainable ones, "they do not offer significant private benefits to users beyond the social benefits of lower carbon emissions" [54]. *Green* electricity, for example, is not *better* at powering our gadgets and appliances than *grey* (fossil) electricity—it is just environmentally more sustainable. What is worse, it is up to now often more expensive and, therefore, even less attractive from the perspective of private utility. Similarly, the electric car so far is not a utility-improving innovation but

has some practical drawbacks like reduced range and long charging procedures; this might change, however, with the development of autonomous driving, which may add new utility, but which would only add significantly to sustainability if it leads to an overall reduction in ownership and use of cars. Hence, most low-carbon technologies today help save materials and energy but may, by themselves, not contribute to a next long wave, which would require a radical expansion of economic activity and new levels of consumption.

In the face of these challenges, Pearson and Foxon warn that "there has been a tendency to neglect or misunderstand the role that the availability of cheap, high quality, carbon intensive energy sources has played in the co-evolutionary developments in technologies, related institutions and business strategies that have underlain the unprecedented economic growth and creation of wealth in Western countries over the past 250 years" [54]. As a consequence they suggest that "for the low carbon transition to really "work", it may prove necessary to transform our energy and related systems and institutions in more profound ways than we have yet acknowledged" [54]. In other words, a new techno-economic paradigm alone may not do [2,50,55,56].

But it is precisely the question of political agency that the TEP framework is somewhat ill-equipped to address. For the TEP framework, technology is the moving force behind development, and it is difficult to influence or forecast future inventions and discoveries. In TEP, technology drives societal change, whereas in a socio-ecological transition the required societal changes would drive the trajectory of technological development. The ontology of the TEP framework grants explanatory priority to the 'landscape level', to use the MLP terminology, whereas 'niches' and even 'regimes' are of secondary importance. Consequently, Geels and Schot admonish that long-wave theory is "too much focused on the macro-environment of socio-technical systems [. . .] and does not provide many insights into how these transitions happen" [22]. Similarly, Köhler contends that "[t]here is no explicit treatment of agency and this means that there is no theoretical basis for proposing ways in which society can influence the development of a Kondratiev wave" [49]. Although some proponents of the TEP framework seem to be aware of this shortcoming and propose to put the question of agency centre-stage on the research agenda [57], the resulting challenge of subjecting socio-technical evolution to societal goals rather than to the 'natural' forces of capitalism appears colossal.

The discussion of the three dominant paradigms in innovation studies so far has revealed severe limitations of evolutionary economic thinking to adequately capturing and responding to the challenges of a transition to sustainability. These limitations, however, are not inherent to evolutionary theory as such, we argue, but result from its reified application to economic theory. While the past socio-technical development of modern societies can be fruitfully described using evolutionary concepts as a heuristic, it would be a mistake to conclude that future change must necessarily be subjected to the same evolutionary patterns, that is, to grant evolutionary patterns of change ontological status. The problem is the level at which the selection environment for processes of innovation is conceptually defined. In economics, the market obviously constitutes a 'natural' selection environment for product innovation. This is all well as long as the only thing that interests the analyst is the economy itself (as an abstract model based on monetary values) and not its relation to the *biophysical* environment. As soon as we are talking about a socio-ecological transition, however, we have to include the biophysical world and its limitations into the analysis, which constitutes the ultimately much more relevant selection environment. Put differently, if economic development is to be constrained by and re-embedded within *scientifically* defined 'planetary boundaries' [58], then the mode of selection has to be different to the normal workings of a market economy, for which the market is the *natural* selection environment. In evolutionary approaches technology is the independent and socio-ecological outcomes the dependent variable, while for a socio-ecological transition the desired outcomes are the independent and technology a dependent variable. Thus, the nature of the market needs to be accommodated within biophysical nature in a way that can only be defined and decided *politically*. The consequence of this is that a transition to sustainability requires a socially constructed, purposively designed set of selection mechanisms that is geared to steering that transition if necessary

against the lure of consumer utility, profitability and the requirements of capital accumulation. This implies that a transition to sustainability is primarily about the *politics of selection* and only in the second instance about technological innovation and consumer choice. A transformative politics of socio-technical selection, however, needs to be based on robust political institutions and requires deep democratic legitimation. In the next section, we present an analytical framework that may help to better understand the challenge ahead and may become beneficial for the design of the institutions required for a seriously transformative innovation policy.

5. 'Agentic Operators' and Transformative Innovation

The framework developed in Hausknost [59] analytically distinguishes three modes of agency or 'agentic operators'. We call them 'operators' because they do different things to reality, just like mathematical operators do different things to numbers. The idea is that just like *addition*, *subtraction*, *division* and *multiplication*, so *decision*, *choice*, and *solution* do different things to the realities they are applied to. The concept of agentic operators offers an analytical framework to explore patterns and strategies of change, as operators are frequently combined in certain ways that result in particular trajectories of change. By applying the framework to evolutionary theorising we aim to show that the latter tends to construct an agentic regime based on the recursive interaction between 'choice' and 'solution', while largely neglecting the potential of 'decision'. There are two distinctive criteria which define the characteristics of agentic operators and which separate them from each other. One is the question whether or not the operator *eliminates the options* that are not selected in the operation. The other is the question whether the operator *selects between incommensurable options* or not, that is, whether or not it involves the need for political decision-making. Each operator combines different answers to these two questions and, therefore, constitutes a unique way of 'processing' reality. Table 1 summarises the resulting typology.

Table 1. Typology of agentic operators.

Operator	Elimination of Options	Incommensurability
decision	✓	✓
choice	-	✓
solution	✓	-

There are three logically distinct operators: decision, choice and solution. According to the two selection criteria identified, they cover all possible modes of agency. Decisions create path dependency in that they eliminate the discarded options: if I decide for X, then Y and Z are eliminated as options. Any future development will have X as its point of departure. Importantly, however, a decision always selects between options that are *incommensurable*, that is, between options that differ at least in one aspect for which there does not exist common rational ground. For example, a government of a coal-rich country might decide to ban the use and export of coal, despite negative economic consequences and some social disruption this might cause. In doing so, it would *eliminate* coal as an option instead of just promoting sustainable alternatives in the energy market and hoping for change to emerge. The decision could be based on the rationality of climate science but might make little sense in the rationality of (mainstream) economics. The act of privileging one rationality over the other—and thus of *deciding*—would ultimately have to be based on values, world views and what is sometimes called ideology. It cannot, by itself, resort to an overarching, neutral rationality that would allow for *only* this particular option.

Decisions, then, are selections between different ways to frame reality, which cannot be compared in objective terms of measurement or calculation. That is why Jacques Derrida defined decisions paradoxically as having to *pass the field of undecidability* [60]. A decision that is *decidable* would not decide anything but reveal the *solution* to a calculable problem [61].

Solutions, therefore, are defined as selections between *commensurable* options, that is, between options that can be assessed and compared within the same rational framework or paradigm. One of the options will be the *best* solution, others will be *less* ideal or even *wrong*—this ranking can be established unambiguously by applying a common unit of measurement or rationality. The selection a solution executes also eliminates the discarded options, just like in a decision: the wrong or second-best options will no longer play a role as soon as the best option is established. A more energy efficient engine, for example, will (ceteris paribus) supplant a less energy efficient one, if energy inefficiency is the problem for which a solution was sought. The ability of solutions to create path dependency, however, is severely restricted, since the path is implicitly pre-selected by the common frame of rationality. The path is calculable on the basis of the common rationality. Solutions only constitute different stages or steps of following the same path.

Choices, finally, are marked by the peculiar trait that they do *not* eliminate the options between which they select. Hence, while the options are incommensurable like in decisions, the ones a choice discards remain in the pool for further selections. A choice can be repeated at will: this time, I select X, next time Y, and another time Z. This feature makes choice the genuine agentic operator of the marketplace: Today I select a Mars chocolate bar, tomorrow a muesli bar, and the next day an organic and fair-trade chocolate bar. The options are incommensurable in that they cannot be ordered according to a one-dimensional rational framework: one day, my preference for the taste of Mars will prevail over my ambition to lead a healthy life and my desire to contribute to the creation of a 'better world'. Another day, the ranking may be reversed on the basis of different moods, cravings or manipulations by adverts [62,63].

While choice is the genuine operator of the market place, solution can be attributed to science and technology. Decision, finally, is the operator of politics proper, by virtue of politics being the name of the *undecidability* of the social: if society were a *decidable* structure, there would be no need for politics in the first place [64]. The typology, it should be mentioned, presents *ideal types* in a sociological sense rather than clear-cut phenomena of social life. In reality, the boundaries are often somewhat blurry in that large investments in a market may take the form of decisions as they actually eliminate other options for an investor, or in that 'solutions' are sometimes highly political when their actual undecidability is (deliberately) disguised under the veil of scientific rationality. But this is precisely the messy terrain we enter when talking about the steering of a purposive transition of society toward sustainability. Such a transition will inevitably require changes in all three variants-solutions to technological problems, choices for individuals and collective decisions to introduce and maintain the required directionality of change. We argue, however, that the transition to sustainability so far has largely been conceptualised as a co-evolutionary process of solutions and choices with little need for conflictual political decision-making. We challenge this naïve conception of transformation and argue that decision is perhaps the most important agentic operator for a societally steered transition process, as it sets the bounds within which solutions and choices need to take place.

5.1. Socio-Technical Evolution as a Matter of Solutions and Choices Only?

As shown above, the evolutionary economics approach to socio-technical change might be ill-equipped to design and prepare an exit strategy *out of* the fossil energy regime. The reason for this is that evolution does not pursue any *normative* goals—it simply evolves on the basis of existing conditions. However, once *normative* objectives for societal development are defined, the mechanisms driving evolution will need to be actively designed according to the *normative* requirements of change.

The mechanisms driving evolutionary change are those of variation, selection and retention. In evolutionary economics, variation is conceptualised as diversity generated through innovation. Selection reduces diversity through acts of choice by boundedly rational individuals and groups [65]. Although selection is considered to be driven by "competition, regulation and institutions" [19], the act of selection itself is understood as the cumulative result of choices that restructure the field of options. Retention, finally, is conceived as the selective replication of technologies and practices

(mainly) through imitation. Here, too, retention is the result of an eventual sedimentation of patterns of choice, which may be stimulated by policies, but has little to do with collective decision-making. Overall, socio-technical evolution is depicted as a co-evolutionary process of demand and supply, which is organised through the complex interaction of solutions (technological change) and choices (consumer preferences) [66]. When conceptualising sustainability transitions, evolutionary economics rely on the micro-meso-macro framework that has also been adopted by the MLP. The micro-level is constituted by individuals and their interactions. Individuals are conceived as carriers of rules, which, in turn, are called 'meso-units' [18]. Rules are acquired problem-solving mechanisms. They always originate from micro-processes on the level of individuals. The macro-level is where rule dynamics are governed and where rules congeal to collective routines and formal regulations. The interplay between dynamics on the micro-level (rule-generation) and macro-level (rule-coordination) creates processes of change that play out at the decisive meso-level, where new configurations of rules may stabilise.

The upshot of all this is that change is the result of myriad individuals solving problems and making choices. The recursive interrelation of all these solutions and choices generate patterns and configurations of stabilised rules, routines and institutions, which, in turn, act selectively on the option space of new choices and solutions. Directionality is thus an effect of aggregate choice. This co-evolutionary coupling of solutions and choices may be *influenced* by policies aiming at individuals and organisations, like tradeable permits and environmental taxes [19] or "ethical consumption and healthy habits" [67], but change remains the cumulative effect of individual action. This perspective seems largely to neglect the idea that democratically constituted societies have the ability, in principle, through institutionally coordinated processes of contestation, deliberation and collective will-formation to make collectively binding *decisions* that restructure the very terrain on which problems are defined, solutions sought and choices made. Put differently, by fetishizing the 'emergent' character of evolutionary change, which simultaneously mystifies change as an opaque process that cannot be willed and steered but only subtly influenced and stimulated, evolutionary thinking reifies an ontology of the market and delegitimises the power of political decision-making. Polities can in principle (and routinely do!)—through parliamentarian, governmental or direct democratic channels—make decisions that delete entire segments of the option space within which choice takes place or open up new segments; they can make decisions that render certain definitions of problems obsolete and, therefore, discard entire categories of solutions. For example, a polity could decide that the internal combustion engine should no longer be part of its socio-technical option-space (i.e., market) and thus ban it. As a consequence, the entire terrain on which solutions (innovations) are sought and choices made would shift to electric and other alternatives by virtue of a collectively willed decision. Of course, the decision would become possible only based on pre-existing technological solutions—but the point is to *decide* for a solution (or category of solutions), and thus to shift the ground of innovation toward a societally agreed terrain. A polity could further decide that products and ingredients that contribute to deforestation and other detrimental forms of land use change will be eliminated from the option space—for example, palm oil and all forms of fibre and produce that do not adhere to defined standards. Consequently, firms would be forced to search for solutions to replace these ingredients or make sure they are produced according to the politically decided standards—and consumers would be left with a redefined field of choice. The point is that in a *purposive* societal transition *directionality* is necessarily a *political* category and *selection* predominantly a political function. Solution and choice play important parts in socio-technical evolution, but it is a mistake to assign them the responsibility for introducing the directionality of change and its long-term retention. As a coupled regime of variation and selection, solution and choice adhere to the criteria of individual utility and commercial viability, which have guided socio-technical evolution in the past but are the wrong criteria to steer a societal transition toward sustainability. A transformative model of innovation will thus have to focus on the design of political structures and institutions that empower society to make decisions for change.

5.2. Towards a Transformative Model of Innovation

There is of course a reason why decisions in the form we introduced them here are unpopular with evolutionary models of innovation thinking. Collective decisions, some evolutionary thinkers fear, may insert a crude and economically inefficient type of directionality that may run into socio-technical dead-ends. Directionality generated through political decisions rather than through the coevolution of solutions and choices might cut off "alternative development trajectories that may turn out to be promising at a later stage, but which are presently unforeseen" [19]. 'Picking winners' through political decisions has a bad reputation in the innovation literature, as it entails risks of ideological bias, vested interests and corruption to prevail instead of the most rational or efficient solution [68]. The underlying assumption is, of course, that the market-driven co-evolution of demand and supply would produce more worthy and evolutionary 'fit' winners. Searching a way out of the dilemma, Stirling proposes that a transformative model of innovation should not be about 'picking winners', but "about engaging widely across society, in order to build the most fruitful conditions for deciding what 'winning' even means" [69]. While we share the qualms about picking specific winners in specific situations, we see an urgent need to define more concretely what a transformative model of innovation has to achieve and what institutional and political preconditions it requires. For example, what does it mean 'to decide what winning means'? Who is to decide and how? And what does it mean to 'engage widely across society' in this context? What specific mechanism of participation and decision-making are required to arrive at transformative innovation that is both effective in introducing strong directionality and supported by the public?

Strong directionality. Given the 'super-wicked' [70] problem of climate change, which requires a swift and radical correction of the established developmental trajectory, a transformative model of innovation needs to be able not only to "create and shape markets" [44], but to insert directionality that—at least initially—goes against the grain of capital interests and commercial viability. Commercial viability may be an *ex post* effect of a transformative innovation, once the conditions for doing business have been redefined according to societally willed standards; but it need no longer be a precondition for successful innovation. This means that the established pattern of what it means to 'innovate' might need to be broken and replaced by forms of change that prioritise societal objectives over private utility and profit accumulation. We call this the power to introduce 'strong directionality' as it requires the political capacity to bend the curve beyond the scope of 'green growth' [71] and 'ecological modernisation' [72]. This implies that innovation goes beyond questions of technology and must be applied to the more fundamental structures of society including the role and distribution of wage labour and other forms of work [73] and even the ways we define, use and distribute property [74]. Transformative innovation, we argue, must not respect the political-economic taboos that shield the institutional core of contemporary capitalist societies. Without entering that core, innovation will fail to be transformative.

Creative destruction and regime destabilisation. The second critical requirement for a transformative model of innovation is that it needs to be both creative and destructive [16,17]. The doors to a sustainable type of civilisation must be opened, but at the same time, doors leading back to the highly profitable and convenient business model of unsustainability must be closed for good. This means that a transformative model of innovation must come to terms with and have an answer to questions of economic and political power and must be institutionally empowered as a *politics* of transformation. Questions of legitimacy, democracy and inclusiveness arise when unsustainable practices, technologies and structures of society are being negotiated and challenged. Scientific scrutiny, public deliberation and democratic will-formation will have to be joined together in novel institutional settings orchestrating processes of transformative innovation [75,76]. Institutions deliberately designed for that purpose need to be equipped with the democratic *power to decide*, which raises complicated questions of political legitimacy and accountability that growth-seeking industrial societies could manage to evade for a long time. Transformation will create losers, at least in the short term (as well as winners). Unlike in socio-technical revolutions of the past that followed the 'natural' evolutionary

trajectories of capitalist expansion, a purposive transformation will have to be politically negotiated to a large extent—and its losers politically accounted for. This is why the *political* nature of transformative innovation needs to be acknowledged and institutionally reflected. This constitutes a novel and unprecedented institutional challenge to modern states and societies. It should be clear that democratic institutions empowered to make transformative decisions by definition cannot guarantee particular outcomes—citizens may indeed decide for convenience and against sustainability in some cases. The point is not to create a naïve conception of unfailing democratic transformation, but to open up windows and mechanisms through which a purposive transformation of industrial societies becomes part of our understanding of what democracy means.

It is beyond the scope of this paper to make concrete proposals for an institutional framework of transformative innovation. However, there are two specific functions that institutions for transformative innovation should fulfil in order to introduce strong directionality and incumbent regime destabilisation: Firstly, institutions on the national or supranational level that define the conditions of what 'winning' means, in the sense expressed above by Stirling [69]. These institutions would combine scientific assessment with public deliberation and democratic decision-making to set the parameters within which societally desirable innovation should take place and is allowed into the field of choice. Such institutions could decide, for example, that technologies, products and socio-technical practices that are likely to further expand the use of fossil fuels, the degradation of natural forests or the further acidification of oceans (even if through rebound or leakage effects) would be severely disadvantaged or even banned by public policy. These decisions would define the bounds of a societally willed trajectory of development without resorting to a politics of picking individual winners.

Secondly, we do believe that in some sectors of transformative innovation, societies need to pick winners after all. This applies, for example, to the field of social and grassroots innovations, where experimentation on the niche level has been going on for many years without much upscaling and mainstream of successful innovations [77,78]. Numerous initiatives around the globe—from low-carbon municipalities and eco-villages to co-operative and solidary models of economy—have proven practicable and sustainable alternatives to the status quo. Most of these alternatives, however, are systematically restrained from breaching the boundaries of their niches and from being normalised and mainstreamed in the heart of modern societies due to institutional and regulatory restrictions or lack of legal and political support. A transformative model of innovation thus needs to entail what Hausknost et al. [79] have called *transmission belt institutions*. These are institutions that are designed to negotiate and decide on the national and sub-national level, by which practicable and sustainable alternatives to the ways "we are doing things" (social practices, economic institutions, work, property, housing, finance) developed in niches around the world should be tested on the *regime* level and then institutionally *implemented* and *mainstreamed*. Far from promoting a planned economy, this model of transformative innovation will require much experimentation, but also the courage to upscale promising social innovations. Here, expert knowledge and democratic procedures of deliberation and collective decision-making will need to be combined in novel and politically powerful ways that enable discourses of social innovation to enter the centre of society and that lead to the implementation of collective decisions that change the very contours of society. *Transmission belt institutions* have the power to overrule market dynamics and incumbent capital interests by redefining bounds to enable the upscaling of innovations by means of democratic deliberation and decision-making. Since the question of demand and supply in social innovations in particular is a political one and cannot be answered by market dynamics, an institutional transmission belt between niches and the regime is required. Otherwise, social innovations remain in their depoliticised state of niche experimentation forever or gradually wither away [80].

As discussed in Sections 2–4, we detect severe limitations of the three dominant paradigms in innovation studies. While we appreciate the underlying theoretical foundations of evolutionary thinking and their analytical capacities regarding past developments, we criticise their market-based

selection environments, which ultimately hinder transformative innovation. We think that the two functions of the institutional framework described above could be valuable in strengthening the political dimension of selection in the three paradigms discussed. In the case of the multi-level perspective, the main transformative task is to manage the all-important interaction between niches and regimes in a purposive and goal-oriented way, while regimes play the role of selection environments for innovations. Exactly for this purpose, institutions on a national or supranational level are needed for constructing selection mechanisms that are ultimately guided by societal goals. Transmission belt institutions would then be needed to implement the societally defined selection criteria by normalising and universalising the diffusion of transformative innovation at regime level. As far as technological innovation systems (TIS) are concerned, the state is already instrumental in strategically creating the conditions for new markets but, still, markets act as primary selector. Here such institutions could instead introduce the primacy of societal goals in TIS and transmission belt institutions could guide the diffusion of new preferred technologies and the emergence of new markets, e.g., when energy efficiency gains or even sufficiency strategies become societally favourable to mere utility gains and accumulation interests. Finally, when discussing a sustainable next Kondratiev wave and a low-carbon industrial revolution, we strongly believe that only carefully designed institutions that replace market driven selection by societal selection mechanisms, would create a chance to leave behind the trajectory of utility-guided and resource-blind socio-technical evolution and to enter a trajectory of purposive transformation according to societally negotiated goals and standards.

6. Conclusions

In this paper, we examined three dominant approaches in innovation theory on a conceptual level with regard to their capacities to contribute to a comprehensive sustainability transition. We analysed the multi-level perspective, the innovation systems approach and the neo-Schumpeterian theory of long waves. All three are ontologically based in evolutionary economic theory. While evolutionary theorising can be very helpful to understand processes of socio-technical co-evolution, the approaches we analysed all share a crucial shortcoming in that they accept the apolitical conception of selection mechanisms at the core of evolutionary economic theory, which defines the market as the most important selection environment for technological (and other) innovations. As the market cannot anticipate future external selection pressures, however, it is an improper selection environment for the implementation of purposive changes aiming at the avoidance of future problems.

What is required, then, we argued, is the internal representation of the external pressures in selection systems other than the market. In other words, we need powerful institutional mechanisms of selection that substitute the mechanisms of the market to some extent and insert strong directionality to processes of innovation. The design and implementation of the institutions necessary for a transformative model of innovation might itself become the most important field of innovation in years to come. The main purpose of these institutions would be to secure the main characteristics of a purposive, normatively directed transformation of society that cannot be controlled by the selection mechanisms of demand and supply. Key among these characteristics is the power to insert and sustain a strong directionality of change and to destabilise the incumbent regime of structural unsustainability. These are political characteristics, which need to be enacted through specifically designed political institutions.

Applying the analytical framework of 'agentic operators' our analysis concluded that current innovation policy is dominated by the operators *choice* and *solution* and thus tied to market selection and incremental technological change. What is lacking are *decisions* that shift the entire terrain on which *solutions* are being sought and that make purposive selections between alternative socio-technological trajectories. *Decisions* are rare because they are irreducibly political and face inherent legitimation problems. Nevertheless, they will be needed in the future to provide the level of steering that is necessary to break out of our carbon economy. We propose to acknowledge the inherently political nature of transformation and to design novel institutions that integrate expert knowledge with

processes of public deliberation and democratic decision-making. These institutions need to be endowed with the power to make binding decisions. We identified two possible functions of an institutional framework for transformative innovation: to set the bounds within which transformative innovation has to take place and to work as transmission belts for the upscaling of practicable (social) innovations that would otherwise remain stuck in niche experimentation.

Author Contributions: Conceptualization, D.H with contributions from W.H; Writing—original draft preparation, D.H.; Writing—review and editing, D.H. and W.H.; Funding acquisition, D.H.

Funding: This research was support by funding through the ESRC Centre for the Understanding of Sustainable Prosperity (CUSP).

Acknowledgments: We would like to thank Joachim Spangenberg as well as the three anonymous reviewers for their valuable comments.

Conflicts of Interest: The authors declare no conflict of interest.

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