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Rethinking the Multi-level Perspective for energy transitions: From regime life-cycle to explanatory typology of transition pathways

Abstract

The mounting challenge of climate change requires large-scale transitions in energy, mobility and agro-food systems underpinning industrial societies. An influential framework for the study of energy transitions is the Multi-level Perspective which has been applied to a broad range of new topics and questions over the last decades. One of the recent key themes is the timing, duration and acceleration of transitions. This paper aims to contribute to this discussion by offering a reformulation of MLP's 'global' model which explains socio-technical system shifts through interacting processes on niche, regime and landscape levels. Through a close inspection of MLP's seminal works coupled with selected insights from other literatures the paper develops two conceptualizations: 1) a regime life-cycle model of transitions; 2) a 'property space' based approach to transition pathways. These formulations enable to establish a common analytical core of various frameworks focused on systems change, open up new research questions, generate new hypotheses, construct an explanatory typology of transition pathways and provide practical methodological guidance for case selection in further research on energy and mobility transitions.

Keywords: energy transitions, multi-level perspective, life-cycle, property space, explanatory typology, transition pathways

1. Introduction

The mounting challenge of climate change requires rapid and radical changes in a broad range of socio-technical systems underpinning industrial societies [1-4]. Because of their substantial social and environmental impacts energy systems (along with mobility, agro-food and housing) are frequently considered crucial for the turn towards sustainability [5]. Responding to this challenge the field of transitions studies has increasingly grown in prominence as reflected in exponential growth of studies devoted to the topic [6]. In particular, the Multi-level Perspective on socio-technical transitions [7-9] has established itself as an influential framework [10]. Having opened up a highly productive way to analyse system innovation, sustainable development and low-carbon transitions MLP continues to be widely applied to the domains of energy and mobility (see [11-14] for just a few recent examples in this journal).

The 'global' model of MLP, proposing that radical shifts in socio-technical systems occur through interacting processes on three levels – niche, regime and landscape –, was initially developed through a series of case studies on transport, waste management and factory production [8, 15-17]¹. This approach was soon criticized for various shortcomings such as its 'structuralist' mode of explanation and lack of agency [20-22], relative neglect of power and politics [23,24], exclusion of the spatial dimension [25], conceptual vagueness [26] and methodological inconsistencies [27]. As a response MLP was gradually extended in different directions, including the development of 'local' models for niche formation [28,29] and regime destabilization [30,31], improving the methodology of transitions research [32,33], conceptualizing the geography of transitions [34,35] and turning more attention to actors and power [36-39].

But the proliferation of studies using MLP has also prompted a certain sense of disorientation. As

¹ Here and throughout the text 'global' refers to a model operating on a high level of aggregation, covering the entire transition process and (often) refraining from specifying niche- and regime-internal processes [18, p. 414]. It does not refer to similar processes operating on different spatial scales such as recent distinctions between 'global' regimes and their local manifestations [19].

expressed by a recent review paper, “authors have made so many and diverse contributions in recent years that there is a risk of not seeing the forest for the trees” [40, p. 24]. This situation has been tackled in various ways. Meta-studies and systematic literature reviews have been increasingly conducted on specific sub-topics of transitions, including actors [41], destabilization factors [42], agriculture and food systems [43], intermediaries [44] and experiments [45]. Another trend is the emergence of various summaries of state-of-the-art empirical research in order to propose overarching [6] and topical research agendas, e.g. on energy demand reduction [40] or the politics of accelerating low-carbon transitions [46]. Yet another response involves reflections on the metatheoretical [47-49] and philosophical foundations of MLP [50,51]. However, these attempts tend to have their own limitations. While meta-studies, literature reviews and agendas excel in summarizing the findings of existing empirical studies they tend to neglect what could have been theoretically observed but, so far, has not. In other words, they tend to prioritize the empirically observed in relation to the logically possible [52]. The metatheoretical and philosophical studies, on the other hand, are often helpful in uncovering the general oversights of MLP but tend to be less useful for directly advancing substantive propositions on how socio-technical transitions occur.

One of the recent key themes concerns the timing, duration and acceleration of transitions. Given that historically energy transitions have taken 50-100 years to unfold there is increasing question of whether such system shifts can be purposefully accelerated: see, for example, [1] and a following debate in Volume 22 of this journal, especially [53-55]. Attempts have been made to measure the formative phase of energy technologies [56-58] and to identify the conditions for the political acceleration of transitions [59-61]. The speed of transitions is also recognized as an important direction in the agenda of sustainability transitions research [6, p. 6]. However, devising interventions for accelerating transitions in energy and mobility systems requires a good understanding of how, when and why transitions occur in the first place.

This paper aims to contribute to this ongoing conversation by rethinking the 'global' model of MLP that conceptualizes transitions in single systems. As such the following seeks to develop two ideas that have remained dormant in the foundational works of MLP – analytical steps that in principle could have been taken by the proponents of the framework but, for one reason or another, were not. More specifically, this paper aims to 1) use the similarities between niches and regimes as a starting point for conceptualizing transitions as being based on a common life-cycle; 2) think of niches, regimes and the landscape in terms of each having varying properties and using the resulting 'property space' for developing a more nuanced understanding of transition pathways. As shown below these conceptualizations enable to advance our understanding of the temporal dimension of transitions in three ways: 1) going beyond the superficial differences between various frameworks focused on systems change (e.g. MLP, Technological Innovation Systems, Large Technical Systems) and establishing their common analytical core; 2) generating new hypotheses and opening up new research questions so far neglected in studies using MLP; 3) constructing an explanatory typology [62] of transition pathways and thereby providing practical methodological guidance for case selection in further research on energy and mobility transitions.

The paper seeks to realize its ambition in a particular way, i.e. through a close reading of the seminal texts of MLP, particularly [8,15,18,63,64], coupled with selected insights from other literature on systems change. For this purpose three theorizing strategies [52] will be mobilized: 1) focusing on broad commonalities between the basic theoretical categories of MLP; 2) thinking through the logical implications of MLP's existing arguments; 3) focusing on the logically possible. By working on the middle-range level of abstraction the article thus seeks not only to highlight the general oversights of MLP but also to improve its propositional content. Hence the paper seeks to be quite pragmatic in its goals: it is successful if the reader find the arguments both interesting (i.e.

somewhat provocative) and useful (i.e. enabling productive research along new avenues).

The paper is structured as follows. After a short summary of MLP section 2 will focus on the differences and similarities of the three levels of the framework: niche, regime and landscape. This will lead to the notion of regime life-cycle and an outline of its phases. Building on this section 3 introduces the idea of the differing properties of niches, focal regime and the landscape, uses existing literature to define the resulting 'property space' of the three and, as a result, identifies 16 logically possible transition pathways. Both sections also outline a set of research questions opened up by these theoretical formulations. Section 4 summarizes the argument, highlights its limitations and offers some concluding reflections.

2. Rethinking transitions from the life-cycle perspective

2.1 Multi-level Perspective: A 'global' model

Transitions can be defined as long-term (50 years and more) shifts from one socio-technical system to another. Socio-technical system refers to a configuration of actors, rules and technologies for the fulfilment of a particular societal function such as energy provision, food production or transportation. This configuration encompasses the dimensions of science and engineering, economy, policy, everyday life and culture. For example, a system of personal land-based transportation entails the mutual alignment of vehicles, road infrastructure, repair shops, dealer networks, production facilities, traffic regulation, users' driving routines and symbolic meanings of the automobile [8, p. 147].

MLP proposes that transitions come about through interrelated processes on three levels: niche, regime and landscape [8,15,63]. Socio-technical regime is defined as a shared, fairly stable and aligned set of rules directing the behaviour of actors in a particular system. These rules are embedded in various elements of the socio-technical system, and they shape innovative activities towards a specific trajectory of incremental innovation (e.g. increased fuel efficiency for cars)². Radical alternatives to regimes are developed in spaces called niches. These are application areas dominated by specific selection criteria that shield the emerging new and unstable technologies from direct market pressure (e.g. military applications prioritizing performance over costs). Finally, 'landscape' represents exogenous macro-level forces such as wars or demographic changes that shape niches and regimes but are not shaped by them (in short and medium term).

Although early accounts [8,65] distinguished four transition phases, later work [38,66] has simplified this to three:

1. Start-up: landscape changes put pressure on the dominant regime which initially attempts an internal fix to its problems. For example, 19th century urbanization exacerbated the low-speed problem of horse-drawn carriages, leading to the introduction of horse-drawn rail cars. The same pressures, however, also provide a 'window of opportunity' for the development of emergent niches such as bicycles [8, pp. 144-192].
2. Acceleration: as the regime becomes further destabilized, it prompts a need for a fundamental transformation of its basic architecture. This involves interactions between the regime and emerging niches and between the niches themselves, e.g. bicycles, trams and automobiles competing with horse-drawn carriages in urban passenger transport [8]. Depending on the situation this process can be more or less competitive in nature, resulting

² Note that MLP often makes a distinction between regimes (a set of rules) and systems (related physical artefacts, social entities and rules). However, this distinction is not consistently followed either in theoretical or empirical works using MLP (see [50, pp. 1273-1274] for this argument). Therefore, for the purpose of the current argument the notions of regime and system can be treated as equivalent.

in a gradual scale-up and alignment of different niches.

3. Stabilization: as the emerging system stabilizes along various dimensions, establishing new production, distribution and consumption routines, a regime shift is completed. The interlinked set of dominant designs and infrastructures, mature business models, standardized regulation and clear user preferences provide preconditions for the rapid adoption of the focal technology of the system, e.g. growth in car density in Western European countries after World War II [67, p. 289].

This 'global' model of MLP was further developed through a systematization of transition patterns, leading to the distinction between various transition pathways [18,64] (see section 3).

2.2 Niches, regimes and the landscape: similarities and differences

As central concepts in MLP the precise definitions of niche, regime and landscape as well as ways of operationalizing them for empirical research continue to be debated, see [26,27,50,68-71]. Nevertheless, in broad terms it is generally accepted in the transitions community that niches represent radical novelty, regimes refer to 'business as usual' and the landscape represents exogenous impacts.

Let us start from the comparison of niches and regimes. At the first glance MLP seems to be premised on the essential difference between the two. To begin with, niches and regimes have fundamentally different ways of fulfilling a particular societal function (such as urban mobility provision) – otherwise there would be no reason for the transition to occur in the first place. This also means that both are characterized by qualitatively different components and structure: for example, the 19th century system of urban passenger transport included horse-drawn carriages, operator-owned fleets of horses and streets as a shared social space whereas its successor was characterized by gasoline-based automobiles, private ownership and separate zones for the movement of vehicles and pedestrians [8, pp. 144-192]. There are also significant differences in degree: compared to regimes the number of actors in niches is lower, the focal technology is more immature and the driving rules are in constant flux [64, pp. 18-19]. Furthermore, the components in niches are loosely coupled and less interdependent: therefore, compared to regimes niches have a smaller structuring effect over their internal activities [64]. As a result, there is an important difference in directionality: whereas regimes tend to be path-dependent and inclined towards incremental innovation, niches are more about path-creation [72] and radical innovation.

However, once one zooms out from these differences to the dimensions along which niches and regimes are compared, one immediately notes that both share a same frame of reference. First, both niches and regimes consist of mutually supporting actors, technologies and rules [63, p. 903]. Second, both can be understood as entities with certain boundaries (although, as indicated above, the specification of these boundaries continues to be a difficult challenge in empirical practice). Third, this means the existence of various individual and collective actors identifying with niches or regimes and engaging in various activities to express their allegiance, e.g. niche actors trying to expand niche markets and regime actors countering these actions³. And fourth, ultimately both aim to fulfil a similar function, e.g. horse-drawn carriage regime and bicycle, tram and car niches providing urban mobility. Recognizing these similarities, some scholars [73,74] have therefore explicitly referred to niches as 'proto-regimes'.

The situation seems to be somewhat different for the notion of landscape. In the earliest works on

³ Although the 'global' model did not explicitly highlight the role of various actors, it has been argued that MLP is actually "shot through with agency" [69, p. 29] given that ultimately transitions need to be enacted by different social groups. Later work has explicitly addressed this issue, e.g. by proposing a typology of actor roles in transitions [39] or by specifying the micro-foundations of MLP [48].

MLP landscape was treated as a macro-structure, a gradient of force making some actions easier than others, “something around us that we can travel through, and in a metaphorical sense, something that we are part of, that sustains us” [7, p. 334]. However, soon after the emergence of a dynamic multi-level analysis of transitions [15] the notion of landscape started to turn more dynamic as well. Van Driel and Schot [75] distinguished between three macro-level factors: rapid shocks, long-term changes and factors that change very slowly (e.g. financial crisis, industrialization and climate change respectively). A dominant approach was crystallized by Geels and Schot [18]. Drawing on Suarez and Oliva [76] they used the combinations of four attributes (amplitude, scope, frequency, speed) to distinguish between different types of landscape events: regular change, hyperturbulence⁴, specific shock, disruptive change and avalanche (see table 1 for an overview). The basic idea was that different types of landscape events would have differing impacts on niches and regimes thereby playing a role in the creation of different transition pathways (see section 3).

Although this approach turned out to be highly fruitful for highlighting the commonalities in what would otherwise be a collection of quite diverse macro-level events, it also means that in the 'global' model landscape is treated in a different manner from niches and regimes. Namely, whereas niches and regimes in MLP are specified in terms of their constituting elements (actors, rules technologies), boundaries, existence of devoted actors and a capability to fulfil a certain societal function, landscape is primarily defined by its impacts on niches and the focal regime. The different actors, factors and mechanisms by which these impacts are produced remain black-boxed. For this reason, landscape has been explicitly recognized as a 'residual' category by the proponents of MLP [26,69]5.

Table 1. Types of environmental change [18, p. 404].

Frequency	Amplitude	Speed	Scope	Type of environmental change	Visualization
Low	Low	Low	Low	Regular
Low	High	High	Low	Specific shock
Low	High	Low	Low	Disruptive
Low	High	High	High	Avalanche

The distinctiveness of landscape is also reflected in how MLP conceptualizes interactions between

⁴ Geels and Schot [18, p. 404] discarded this type, arguing that it was unlikely to occur in landscape dynamics.

⁵ This also means that what is considered 'landscape' depends on how the unit of analysis is defined: in single system transitions, conceptualized by the 'global' model, the term refers to everything beyond emerging niches and the focal regime, including other systems. However, in the case of multi-regime interaction [77-79] the notion of landscape would be pushed further beyond the focal systems.

three levels. Namely, interactions between niches and regimes involve transformations in their identity: transitions involve niches scaling up, linking to each other and turning into regimes whereas formerly dominant regimes decline and revert to niche status. For example, in a study of shipping transition [15] the sailing ship regime was initially challenged by the steamer niche and eventually replaced by a steamer-based regime. Conversely, sailing ships were relegated to niche status where they continue to exist to date. In comparison, in the 'global' model landscape events often have a one-way impact on incumbent regimes and emergent niches destabilizing the former and facilitating the latter, e.g. the opening of the Suez canal favouring steamer-based naval transport over sailing ships [15, p. 1269]. Even if it is theoretically acknowledged that in long term regimes can also influence the landscape (see, for example, the well-known figure in [18, p. 401], the change in identity – regimes turning into landscape – is not explored by the model⁶.

Based on the foregoing discussion we can therefore conclude that a) when compared along the dimensions of constituting elements, boundaries, agency and societal function landscape constitutes a category analytically distinct from niches and regimes; b) niches and regimes, on the other hand, should not be seen as fundamentally different types of entities but rather members of the same class; c) among other processes, transitions entail change in the identity of niches and regimes. For this reason let us leave aside a) for a moment. Furthermore, for the sake of analytical clarity let us temporarily imagine a simplest case of transition involving only one niche and one regime. The combination of the logical implications of b) and c) would then lead us to the following formulation: *underlying the 'global' model of transitions is the interaction of two regimes in different phases of their life-cycle*. In the following we will flesh out this idea in more detail.

2.3 Regime life-cycle

Since MLP was initially developed to understand how radical shifts in socio-technical systems occur it has so far conceptualized various transition phases but not the phases of evolution of entities part of this transition (i.e., niches and regimes). However, life-cycle perspective has been adopted in other frameworks on system innovation which can serve as useful analytical building blocks for developing the notion of a regime life-cycle. In particular, Markard [80] has recently distinguished between four phases in the development of Technological Innovation Systems: formative, growth, mature and decline (see table 2). Similar reasoning has been pursued in Large Technical Systems field where Hughes [81,82] has described the phases of invention, development, innovation and growth, competition and consolidation with Sovacool et al. [83] adding reconfiguration, contestation and stagnation and decline⁷.

Table 2. Four phases of a TIS life cycle [80, p. 7].

	Size & actor base	Institutional structure & networks	Technology performance & variation	Context & TIS-context relationship
Formative phase	Sales close to zero Little growth Small number of actors	Low structuration High degree of uncertainty	Performance parameters unclear Performance low	TIS depends on context and adapts to it

⁶ By relating transitions in single systems to long waves and most durable traits of industrial societies, an industrial modernity, a recent Deep Transitions framework [3,4] is an explicit attempt to partially endogenize the notion of landscape.

⁷ Hughes [82, p. 57] mentions transfer as an important part of system development but also argues that this takes place during all phases [82, p. 66]. Similarly, the concept of 'technological style', identified as a separate phase by Sovacool et al. [83], actually refers to the adaptation of a system to specific local characteristics, again a process cross-cutting different phases. Therefore, it does not make sense to treat them as distinct phases of system evolution.

	High degree of vertical integration Low entry/exit rates	Cognitive institutions central Loose networks, incomplete value chains	compared to existing technology High degree of variation	First ties emerge
Growth phase	Sales are moderate at first but grow rapidly Medium to large number of actors in different roles Specific associations & intermediaries emerge High entry rates Strong competition and struggles over standards	Increasing structure Markets take shape Technology-specific institutions emerge Increasing formalization Collaboration in networks	Performance parameters clear Performance increasing Variation decreasing Potential emergence of dominant design	Ties to context multiply and formalize TIS has increasing impact on context Potential conflicts arise Co-dependence
Mature phase	Sales are high Low growth Medium to large number of actors High degree of specialization Low entry/exit rates Potentially dominant players Little conflict	High degree of structuration Uncertainty low Established markets, value chains and networks	Performance increasing Potential branching of technology to new application contexts	High number of close ties Interaction of TIS and context Co-dependence
Decline phase	Sales below maximum and declining High exit rates Intermediaries lose influence Increasing conflict	Structural destabilization Norms/designs questioned Struggles over institutions Networks break up	Performance parameters potentially questioned	Ties break up Dependent context structures decline as well

The basic observations in TIS and LTS literatures can be seen as complementary. On one hand, Markard's [80] distinction between formative and growth phases seems an apt summary of many aspects of early system growth, including invention, development, innovation, growth and competition (in the parlance of LTS). On the other hand, LTS includes a more nuanced account of latter phases of system development by distinguishing between consolidation and gradual internal reconfiguration of mature systems and adding the idea of major contestation of the system before its stagnation and decline. Based on these insights it is possible to divide the life-cycle of a regime into six phases:

1. Emergence: the emergence and partial alignment of radical technological and social niche innovations, providing various building blocks of the future system. For example, before Thomas Alva Edison took a systematic approach to electric lighting in the 1870s, around 20 different types of incandescent lamps had already been invented [84, pp. 73-74]. The innovations embody various economic, political and social characteristics that increase their fit with the environment, e.g. Edison's electric light system was influenced by his awareness of the price of gaslight [81,82]. Since many inventions have a long pre-history, the emergence phase might be quite protracted. This phase roughly matches the formative phase of TIS.
2. Upscaling: as various technological and social innovations mature and align to each other, a

complex system characterized by physical components, manufacturing, sales and service facilities, regulative models, characteristic user practices and cultural meanings, is gradually developed. For example, from the 1880s public lighting in American cities was often perceived as an indicator of modernity for European observers; more broadly, since electrification served many urban needs it became a symbol of progress [85, p. 63]. This phase can also entail increasingly competitive relations between emerging and dominant systems (e.g. gas vs. electricity) and between emerging systems themselves (e.g. AC vs. DC in the 1880s) [81,86]. By increasing the size of the system actors attempt to increase the control of the system over its environment, e.g. Edison's strategy of incorporating various urban utilities to its energy system [82]. This phase matches the growth phase of TIS.

3. Consolidation: the solving of bottlenecks holding back the development of the system as a whole such as the invention of a holding-company form to coordinate vertically integrated utilities in the 1920s [82], and a turn toward largely incremental improvements culminates in the crystallization of the features of a dominant system. From this point forward the system obtains a 'technological momentum' – mass of technical, organizational, institutional, social and cultural components, velocity (rate of growth) and a dominant direction of development – and increasingly starts to shape its environment [82]. This phase matches the first half of the mature phase of TIS.
4. Reorganization: over time pressures on the system start to accumulate but control over the system remains stable. This may lead to gradual reorganization of the system in various ways such as territorial interconnection and cross-linking (e.g. the co-evolution of telegraph and railway), unselecting undesirable users (e.g. British telecommunications networks excluding customers in rural areas or impoverished areas in cities), or repositioning whereby systems gradually reorient their activities in response to external pressures [83]. This phase matches the second half of the mature phase of TIS.
5. Destabilization: as more time passes the problematic aspects of the system become more and more accentuated through drift and crisis. The former refers to the efforts of the incumbent actors to retain their position despite major changes in the system's environment, e.g. the continued attempts to stabilize the heavily-polluting Estonian energy system based on oil shale despite increasing climate change agenda [87]. The latter refers to the contestation of the system because of a large external shock, e.g. the impact of series of railway accidents in the UK between 1993-1997 leading to institutional and financial restructuring of the system [83]. This phase matches the first half of the decline phase of TIS.
6. Stagnation and decline: as the system growth slows down, it starts to lose ground to other systems. Over time the system might be downscaled into a 'luxury' niche (e.g. despite having ceased to be a dominant mode of urban transport already in the 19th century, horse-drawn vehicles are still used for joyrides in various cities) or it might disappear altogether [83]. Similarly to the first phase stagnation and decline may take a long time. This phase roughly matches the second half of the decline phase of TIS.

In transitions narratives one usually encounters regimes in phases 4, 5 and partly 6: the dominant actors, technologies, rules and linkages between them are initially reorganized through various attempts of regime optimization, then further destabilized and eventually transformed in a radical manner. The full trajectory of decline is usually excluded, however, as this takes place after the focal shift. The description of niches is restricted to phases 1 (partly), 2 and 3, involving gradual alignment of a loose collection of actors, technologies and rules into a specific configuration, its subsequent scale-up, interaction with other niches and the incumbent regime, and eventual breakthrough and consolidation. The prehistory of specific niches, often dating back to decades before the focal transition is usually excluded. In sum: rather than surveying the full life-cycles of two regimes, the 'global' model of MLP focuses only on some but different phases of each of them.

These life-cycle phases can be connected to transition phases as follows: start-up would involve the interaction of niches in the (late) emergence phase (1) with a focal regime in reorganization phase (4), acceleration would involve niches in upscaling phase (2) and the focal regime in the destabilization phase (5), whereas stabilization would involve niches in the consolidation phase (4) and the regime in (early) stagnation and decline phase (6). Figure 1 depicts these dynamics (note that in order to convey the idea of the life-cycle both entities on the figure have been labelled 'regime' whereas in conventional MLP terms regime 2 would be initially called 'niche').

Figure 1. Transitions as interactions of regimes in different phases of their life-cycle.

Although the above formulation should only be considered a tentative sketch it opens up interesting possibilities for transitions studies. Namely, it makes it possible to view regime life-cycle as a common analytical core of all “founding theoretical frameworks” [6, p. 4] of the sustainability transitions field – Multi-level Perspective, Technological Innovation Systems, Strategic Niche Management and Transition Management (and also the Large Technical Systems framework). From this perspective these frameworks would mainly differ in terms of their respective emphases on particular stages of the life-cycle as well as the number of regimes usually analysed: whereas SNM, TIS and LTS have largely focused on one system and early phases of development, MLP and TM have mainly analysed multiple systems in differing phases of development⁸. Therefore, fleshing out the regime life-cycle model can serve to bring the various approaches closer by better highlighting their underlying similarities and possible complementarities. It might also help to prevent over-emphasizing the differences between various frameworks which tends to promote the emergence of parallel specialized vocabulary for describing essentially similar processes as evidenced, for example, in the presence of largely unexplored overlaps between the 'functional' approach to TIS-s [89,90] and MLP's niche-formation model [28,29].

In terms of theory development life-cycle thinking for energy transitions can be advanced in three ways:

1. As the regime life-cycle model presented above was based on the insights of TIS and LTS, it primarily focused on technological, economic and, to a lesser extent, institutional developments. However, the evolution of socio-technical systems also entails shifts in user practices and cultural meanings. For example, existing works have proposed that different transition phases are dominated by specific types of users and characterized by particular

⁸ Note that this claim refers to a general tendency with many exceptions. For example, Bergek et al. [88] have conceptualized interactions between multiple TIS-s, whereas many 'local' models of MLP zoom in on particular sub-dynamics of transitions such as niche-construction [29] or regime destabilization [30].

- patterns of contestation [38,66]. Therefore, the question is how do social and cultural elements of socio-technical systems map onto different phases of the regime life-cycle?
2. The regime life-cycle idea is premised on the idea that on a certain level of analytical abstraction niches and regimes can be seen as similar in terms of constituting elements, boundaries, agency and function. This reasoning might also be extended to the internal dynamics of both. For example, recently de Haan and Rotmans [39] have proposed a general typology of actor roles in transitions, cross-cutting niches and regimes. Similarly, TIS literature has developed a list of activities (or 'functions') driving innovation systems in various phases of development [89,90]. A theoretical synthesis connecting actor roles and activities to phase-specific outcomes (e.g. regime-formation, regime reproduction or regime dissolution), explicitly incorporating the role of agency, remains to be undertaken.
 3. The use of life-cycle models is fraught with certain tension: conceptually they present an ideal-type sequence of events [80, p. 2] whereas empirically one often observes many halts, overlaps and backtracks between phases, e.g. [82, p. 50;83, p. 1088]; see also [91, p. 72] for a similar argument on industry destabilization. This indicates a need to develop process theories able to explain various forward and backward shifts between phases. Some attempts in this direction have already been made, e.g. Geels et al. [92] have studied the role of actors in switching from one transition pathway to another whereas Sovacool [1] has suggested multiple drivers accelerating future transitions. However, in addition to theories on positive outcomes (i.e. cases in which transitions occur or are accelerated) deeper understanding is also required on the conditions in which transitions are a) delayed, i.e. emerging regimes getting stuck in one phase; b) reversed, i.e. emergent regimes losing their momentum and declining regimes re-consolidating their position (see [93] for the example of coal), or; c) entirely blocked, amounting to a transition failure, see [94].

Methodologically, the life-cycle conceptualization directs attention to the need for developing multi-dimensional indicators in order to be able to determine the start and end points of each of the six phases. As suggested by Markard [80] the indicators should include actors, institutions, technologies and contextual ties to which one can add dominant actor roles, activities and internal alignment. Insights from industry life-cycle theory and diffusion theory have already proved useful in developing such indicators for energy transitions [56,57,95]. The existence of a diverse portfolio of such standardized indicators would possibly facilitate the formal modelling of more complex transitions cases, e.g. ones involving multi-niche and/or multi-regime interactions.

3. Opening up the property space of transition pathways

The previous section has outlined a six-phase regime life-cycle, imagined transitions as interacting niches and regimes in different parts of their life-cycles, and shown how this conceptualization relates to the three-phase model of transitions. However, in so doing the discussion omitted two important aspects. First, it excluded the role of the landscape, an essential part of MLP's explanation of how and why transitions occur. Second, it did not address a well-established finding from the literature that transitions occur through specific pathways. This suggests that there must be more to MLP's 'global' model than mere phase sequences. To incorporate these aspects the following section will therefore develop a property-based view of transitions, using it to highlight the limitations of existing thinking on transition pathways and to offer a broader perspective enabling a more systematic approach to empirical research on energy transitions.

3.1 The properties of niches, regimes and landscape

Transition pathways were first introduced by Geels and Schot [18] who distinguished between reproduction, transformation, de-alignment and re-alignment, technological substitution,

reconfiguration (and a sequence of these) patterns⁹. This article established a dominant framing on both the role of the landscape (see the previous section) and transition pathways. Indeed a great majority of subsequent studies, e.g. [96,97] to take two recent examples, have adopted the typology at face value. This also includes the authors of the original study. For example, Geels et al. have analysed the role of agency in the enactment of transition pathways. Whereas this led to a refined specification of particular configurations of actors, technologies and rules for each pathway [92, p. 900] the pathways themselves remained the same.

However, this dominant way of employing the typology tends to obscure the fact that it was originally intended to systematize the pathways that had so far been empirically observed. It did not – and indeed, was not meant to – cover every logically possible pathway. The difference between empirically observed and logically observable is significant though because it implies that the typology may, in fact, turn out to be only a partial representation of all possible transition pathways and thus not as exhaustive as it might first seem. In order to start unpacking the full implications of this line of argument let us therefore start from a simple question: what exactly do the three levels 'do' in the 'global' model in order to produce transitions?

Recall that section 2 established the capability to fulfil a particular societal function such as mobility, food or housing as one of the common features of both niches and regimes. It is fairly easy to think of this capability as a property of different niches and regimes: for example, at a given point in time in the 19th century, horse-drawn carriages might have been more effective in delivering urban mobility than automobiles but less so than trams. Furthermore, section 2 argued that landscape in the 'global' model is primarily defined by its twofold impact: destabilizing the regime and facilitating the development of different niches, e.g. 19th century urbanization exacerbating the limitations of horse-drawn carriages and stimulating the emergence of bicycles, trams and automobiles [8, pp. 144-192]. Again, the general capability of the landscape to exert these impacts may be thought of as its property¹⁰.

Having established the possibility of thinking about the three levels of MLP in terms of each having certain properties the next question concerns the possible variation of these properties. Again, the foundational works of MLP can be interpreted as offering important clues in this regard. Consider the following findings of MLP:

1. The impact of moderate landscape pressure (disruptive change) has been argued to give regime actors enough time for internal readjustments (transformation pathway; see [64, pp. 58-63] for a summary of the Dutch transition from cesspools to sewer systems). In contrast, more rapid pressure (avalanche change) tends to open up the regime for competing niches. This can be interpreted as a statement about the differing capability of the landscape to shape niche-regime interaction.
2. Geels [8, pp. 265-266] has argued that Large Technical Systems (e.g. electricity, telephone

⁹ Papachristos et al. [79] later added a new system emergence pathway but remained somewhat unclear about its driving factors. For this reason it has been excluded from the following discussion.

¹⁰ One of the reviewers highlighted that landscape pressures can have differential impacts on regimes and hence it is questionable whether it is meaningful to speak of such pressures as constituting a single category. This echoes an argument from existing transitions literature that landscape pressures do not have a 'mechanical' impact but are "mediated by actors' perceptions, negotiations and agenda setting" [64, pp. 25-26]. I certainly agree about the existence differential impacts. However, I would also point out that similar issues exist almost everywhere: for example, a new drug might have quite different effects on different participants in the treatment group. Yet the overall 'average treatment effect' might still be higher than that of the control group (see also Gerring [98, pp. 220-224] for more discussion on various treatment effects). Thinking in terms of averages across multiple social groups part of the regime thus enables to distinguish between the impacts of a landscape event vs. its absence but also in terms of varying intensity of different landscape events.

networks) are particularly prone to follow the reconfiguration pathway because they cover vast geographical areas and include a number of interrelated, often infrastructural technologies. For example, the emergence of mass production in USA can be described as a gradual change in the basic architecture of the production system, ultimately resulting in a qualitatively novel configuration (see [64, pp. 73-76] for a summary of this case). This implies that some regimes are more resistant to radical upheaval than others.

3. If rapid landscape pressures occur when niches are readily available, transitions are likely to occur through the technological substitution pathway; if niches are immature, de-alignment and re-alignment pathway, including a competition between different niches, is a likely outcome instead. Whereas the former pathway describes a shift from sailing ships to steamers [64, pp. 68-71], competition between bicycles, trams and automobiles was a characteristic feature of the US transition of urban passenger transport [64, pp. 63-68]. These examples highlight that the stage of development of niches might shape transition outcomes.

Based on the above discussion we can therefore conclude that: a) niches, regimes and landscape can be thought of as having certain properties; b) these properties relate to the capability to fulfil a specific societal function (niches, regimes) and to destabilize regimes/stimulate niches (landscape); c) these properties can vary for each of the three levels. However, the above examples also allude to another idea integral to the explanation of transition pathways. As expressed by Geels and Schot:

“...different timings of multi-level interactions have different outcomes. Particularly important is the timing of landscape pressure on regimes with regard to the state of niche-developments. If landscape pressure occurs at a time when niche-innovations are not yet fully developed, the transition path will be different than when they are fully developed” [18, p. 405]. Taken together, this leads to the following formulation: *transition pathways result from the different conjunctions of the varying properties of niches, focal regime and landscape at a particular point in time.*

Before proceeding the somewhat heretical nature of this line of reasoning should be explicitly acknowledged. I realize that some are likely to restrict the foregoing formulation on the grounds that it depicts MLP as a 'variance theory' whereas it is argued to be a 'process theory' instead, see [64, pp. 93-97]. In my view the contrast between 'variance' and 'process theory' is over-stated for time and event sequences present in process theories can be readily incorporated into 'variance theoretical' models. In fact, many scholars in the field of business and management studies, where this distinction was first made [99], focused on organizational processes to find missing variables in their existing models, to quantify the process characteristics and to subject them to statistical analysis [100,101]. Hence in that literature the ultimate aim of 'process theory' was to contribute to 'variance theory', a point which the casual defence of MLP seems to have missed. Furthermore, recent advances in multi-method research frequently advocate combining process- and variable-oriented approaches, e.g. regression analysis and process-tracing [102,103]. Therefore, rather than debating whether the property-based approach is 'reductionist' towards MLP I find it more productive to focus on the whether this move allows to achieve added analytical traction. As the following aims to demonstrate I believe that the answer is affirmative.

3.2 The property space of transition pathways

The tendency to over-emphasize MLP as a 'process' theory likely also explains why, despite the fact that various empirical examples from the foundational works of MLP can be interpreted as containing important hints about the varying properties of niches, regimes and the landscape, , an explicit property-based approach to transition pathways has yet to be attempted. In other words, neither the properties of niches, regimes and landscape nor their internal variation have been made explicit in existing literature. Let us therefore begin the section by taking this additional step.

Building on the empirical illustrations of the previous section one can identify three properties with differing values:

1. Intensity of landscape pressure: the degree to which landscape is able to exert pressure on the incumbent regime and to stimulate niche development. The intensity of landscape pressure can be low (regular change), moderate (disruptive change), high (specific shock) or very high (avalanche).
2. Regime resilience: the degree to which the regime is able to resist external pressure and to co-opt niches without fundamental transformations in its basic architecture (stability of its constituent network of actors, technological performance, guiding rules and overall degree of organization), mode of operation and direction of evolution. This resilience can be low (fragile regime) or high (resilient regime).
3. Niche maturity: the degree to which the niche has become stabilized along various dimensions (network of actors, technological performance, stability of rules, degree of organization). Maturity can be low (emergent niches) or high (mature niches).

The combination of 4 types of landscape change, 2 degrees of regime resilience and 2 degrees of niche maturity gives us a 'property space' [62,104] of 16 possible combinations visualized in table 3. This logically raises the question of how this property space relates to transition pathways identified in existing literature.

Table 3. Possible conjunctions of the varying properties of niches, regimes and the landscape.

Landscape	Niche	Resilient regime	Fragile regime
Regular change	Emergent niches		
	Mature niches		
Disruptive change	Emergent niches		
	Mature niches		
Specific shock	Emergent niches		
	Mature niches		
Avalanche	Emergent niches		
	Mature niches		

To highlight the significance of this analytical move, let us therefore turn the tables on the original typology. For this purpose the definitions of transition pathways by Geels and Schot [18]¹¹ will be assessed in terms of their informative value about the three properties and their variations as specified above. This leads to the following table.

Table 4. The presence of different properties in the typology of transition pathways (based on [18, pp. 406-413]).

Pathway	Description	Information on varying properties		
		Intensity of landscape pressure	Regime resilience	Niche maturity
P0: Reproduction	If there is no external pressure ('regular change' ...), then the regime remains dynamically stable and will reproduce	Low (regular change)	–	–

¹¹ P5 (sequence) has been omitted as it contains a combination of pathways.

itself

P1: Transformation	If there is moderate landscape pressure ('disruptive change') at a moment when niche-innovations have not yet been sufficiently developed, then regime actors will respond by modifying the direction of development paths and innovation activities	Moderate (disruptive change)	–	Emergent
P2: De-alignment and re-alignment	If landscape change is divergent, large and sudden ('avalanche change'), then increasing regime problems may cause regime actors to lose faith. This leads to de-alignment and erosion of the regime. If niche-innovations are not sufficiently developed, then there is no clear substitute. This creates space for the emergence of multiple niche innovations that co-exist and compete for attention and resources. Eventually, one niche-innovation becomes dominant, forming the core for re-alignment of a new regime	Very high (avalanche)	–	Emergent
P3: Substitution	If there is much landscape pressure ('specific shock', 'avalanche change', 'disruptive change') at a moment when niche innovations have developed sufficiently, the latter will break through and replace the existing regime	Very high, high or moderate (avalanche, specific shock, disruptive change)	–	Mature
P4: Reconfiguration	Symbiotic innovations developed in niches are initially adopted in the regime to solve local problems. They subsequently trigger further adjustments in the basic architecture of the regime	Moderate (disruptive change)	Resilient	–

The results of this exercise have somewhat surprising implications¹². Strictly speaking, *since there is at least one unspecified dimension for each pathway, it follows that we are unable to tell which conjunctions of the three properties are related to particular pathways and which ones are not*. For example, the typology tells us that transformation pathway is characterized by moderate landscape pressure and emergent niches. But we do not know whether the regime needs to be fragile, resilient or whether it can be both – all we know is that transformation pathway would occur at least in one of these cases. Less strictly, it is possible that transitions are characterized by equifinality in which case sixteen different starting points would eventually converge to five basic pathways. To use the previous example, moderate landscape pressure and emergent niches would be sufficient to produce the transformation pathway and the properties of the regime would not matter. Although both are plausible interpretations it is important to stress that the existing typology provides insufficient information for deciding the matter, warranting further empirical research.

Depending on the analyst's inclination this research can proceed either by exploratory or

¹² At least to the author.

confirmatory manner. In all these instances, however, table 3 can be used to select empirical cases in a more systematic manner:

1. The above discussion implies that fitting new cases to existing typologies might be a risky strategy since it tends to neglect the possibly important differences in the properties of niche, regime and landscape that, in turn, may be associated with various transition pathways, not only the ones specified in existing work. Hence table 3 could be used for re-interpreting existing case studies, ideally in a form of a meta-study.
2. An exploratory strategy would be to focus on the combination of particular attributes in a single cell (e.g. emergent niche, fragile regime and disruptive change) while remaining agnostic about the expected outcome. Such a strategy would potentially enable to discover new pathways that have not been described by the existing typology.
3. The table can also be used for comparative case study design. For example, it is possible to select cases which are similar along two dimensions (e.g. avalanche change and emergent niches) but differ along one dimension (resilient vs. fragile regime) to find out whether the corresponding pathways differ.
4. Given the existence of a wide variety of frameworks for technological change it is also possible to formulate two competing explanations for a single cell, one based on MLP, one on another theory. Such a research strategy could highlight the explanatory limits of MLP and allow for clearly bounded conceptual extensions, i.e. drawing on the strengths of an alternative framework to increase the accuracy of MLP in explaining a particular outcome.

3.3 Transition pathways: Towards an explanatory typology

As previously argued MLP currently contains insufficient information for connecting particular conjunctions of the properties of niches, regime and the landscape to specific pathways.

Nevertheless, it is possible to draw on the existing typology to formulate educated guesses about the expected outcomes for all 16 possible combinations and to construct a tentative explanatory typology [62] of transition pathways. Doing so highlights the possibility of a fifth, confirmatory research strategy: testing hypotheses on expected pathways on empirical cases to see whether they match the observations and if not, then for what reason. These hypothesized outcomes have been presented in table 5 and will be justified below.

Table 5. A tentative explanatory typology of transition pathways.

Landscape	Niche	Resilient regime	Fragile regime
<i>Regular change</i>	<i>Emergent niches</i>	Reproduction (strong)	Reproduction
	<i>Mature niches</i>	Reproduction	Reproduction (weak)
<i>Disruptive change</i>	<i>Emergent niches</i>	Reconfiguration	Transformation
	<i>Mature niches</i>	Transformation	Technological substitution
<i>Specific shock</i>	<i>Emergent niches</i>	Transition in limbo	Transition in limbo
	<i>Mature niches</i>	Reconfiguration	Technological substitution
<i>Avalanche</i>	<i>Emergent niches</i>	De-alignment and re-alignment (weak)	De-alignment and re-alignment (strong)
	<i>Mature niches</i>	Technological substitution (weak)	Technological substitution (strong)

In the context of regular change reproduction can be assumed to be the outcome in each case. If the regime remains resilient niches would have trouble breaking through regardless of their degree of

maturity; even if the regime is fragile the immaturity of niches would mean that there are simply no good substitutes available. Things might be somewhat different with the conjunction of regular change, fragile regime and the availability of mature niches where the overall situation may be quite unstable. In this case a shift away from reproduction to another pathway might be triggered even by a landscape pressure of low intensity. Alternatively, in the latter conditions one might even ponder the possibility of an endogenous transition, i.e. transition occurring in the absence of major landscape pressures (see [105] on a recent study of such possibility in the case of Dutch dairy farming).

Disruptive pressures unfold slowly but intensify gradually. If niches are not immediately available and the regime remains resilient one might expect a long stretched-out co-evolution of niches and the focal regime, involving gradual changes in the basic architecture of the system, i.e. a reconfiguration pathway. The ready availability of niches might lead to quicker adoption by regime insiders and hence to a transformation pathway. A similar outcome might be expected in the contrary situation: a fragile regime but no immediate availability of niches. In this context regime insiders would be sufficiently motivated to make readjustments but the scale-up of niches would take time, leading to a situation in which regime actors have enough time to adapt. However, this time is taken away from regime insiders when niches are readily available and disruptive change has considerably intensified: in these conditions technological substitution might occur instead.

Matters are more difficult with specific shock as its impact seems to be relatively little studied. For emergent niches one can hypothesize the following sequence: although the specific shock raises an urgent need for change, there is simply no niche to be adopted in the short term. As a result resources will be directed to both optimizing the regime and developing the niches. Niches are likely to be stimulated more if the regime is fragile and hence under more pressure, and less if the regime is resilient. However, as the shock passes the immediate need for a broader transformation also comes to an end. Hence the transition may remain in a limbo state until another landscape pressure opens up a new window of opportunity.

Tentative evidence of this outcome can be found in the experience of postwar mobility systems. The oil crises of 1973 and 1979 were major shocks to industrialized countries heavily dependent on the resource as one of the core inputs [106, p. 298]. These events coincided with increasing contestation of the car-based mobility regime on various grounds such as safety, emissions and urban congestion [107,108]. This promoted various responses including the development of electric vehicles that, for a limited period, were internationally perceived as cars of the future [109-110], increased interest in Toyota's Production System or attempts to envision the future of the automobile such as the International Motor Vehicle Program at MIT [111]. Ultimately the impact of oil crises turned out to be lower than initially expected [106, p. 298]. This also meant that the mobility systems in developed countries, based on the individual use of privately-owned gasoline-based vehicles, largely remained in place. However, system-internal responses in many countries included increasing use of smaller and more fuel-efficient cars [112] and the adoption of Japanese car production techniques in USA and Europe [113].

When specific shock occurs while the regime is resilient and niches mature, one might expect quick attempts by the existing regime to absorb the niches without major changes to its basic underlying architecture, resulting in a reconfiguration pathway. When the regime is fragile, however, even a shock of relatively modest scope might trigger the technological substitution pathway.

Lastly, avalanche change is likely to open up an urgent need for broad transformation on many fronts. If niches are not readily available one might expect de-alignment and re-alignment pathway

to occur whether the regime is resilient or fragile. The main difference is that in the former case the transition is likely to be drawn-out and longer as regime incumbents have more power to resist and delay niche scale-up. If niches are mature, however, one might expect considerable niche-regime competition, leading to technological substitution. The likelihood of a transition is even higher when the regime is fragile.

A broader implication of viewing transitions from the property-based perspective is that there might be more to transition pathways than meets the eye. Similarly to the regime life-cycle model proposed in section 2 this formulation opens up various research questions, some following directly from the conceptualization, some directing attention to additional factors overlooked in existing work. More specifically, one can identify three possible directions of future research:

1. Are transitions characterized by equifinality or not? Can any new pathways be discovered? Does further work confirm or disprove the above predictions on transition pathways as specified above? What might explain the deviations?
2. The above conceptualization has implicitly treated the degrees of niche maturity and regime resilience as functions of time. However, are there additional factors shaping their properties? In other words, are some regimes inherently more fragile or some niches inherently more difficult to scale up? What determines this capacity?
3. The above formulation also focused on the nature and strength of the properties of the three levels. However, it did not address another crucial dimension, the duration of pressures exerted by the three levels. For example, how long should a landscape pressure of a specific type last in order to lead to transitions? Does it need to be present in all transition phases or only some of them? Conversely: is there a point from which the dynamics between niche-construction and regime decline become self-sustaining, i.e. relatively independent from the initial facilitating landscape pressure?

This explanatory typology enables to build on recent work on the role of structural and agentic factors in accelerating transitions [59-60] or the identification of critical policy intervention points in different transition pathways [61]. A more nuanced understanding of the conditions in which transitions happen (or fail to do so) might help to assess the likelihood of success of particular policy strategies. For example, in the context of weak reproduction a deliberate push towards change by a coalition of actors might be much more easily achieved than in the context of strong reproduction. This, however, also directs more attention to the need for further work on operationalizing landscape pressure intensity, regime resilience and niche maturity with sufficient precision.

4. Conclusion

This paper has sought to rethink the 'global' model of the Multi-level Perspective on socio-technical transitions in order to advance research on energy and mobility transitions. More specifically, it sought to develop two ideas dormant in existing transitions literature. Section 2 outlined a six-phase regime life-cycle and made a case that transitions could be conceived as an interaction of niches and regimes in different phases of their life-cycles. It also argued that regime life-cycle could be seen as a common analytical core of five existing frameworks focused on system innovation. Section 3 explored the possibility of thinking about transition pathways in terms of conjunctions of varying properties of niches, focal regime and landscape. The implications of these conceptualizations were used to highlight the limitations of existing thinking on transition pathways, generate new hypotheses, construct a tentative explanatory typology of transition pathways, provide methodological guidance for case selection and open up new research questions for the study of energy and mobility transitions.

The paper has also certain limitations. First and foremost, as the article was theoretical in nature, no primary research was conducted. Although that does not mean that the argument was unsupported by evidence – after all, the studies used in the analysis had based their claims on empirical data – it does mean that more research is required in order to validate (or not) propositions on regime life-cycle and transition pathways. Furthermore, because of its theoretical focus the article did not devote much space on operationalization. Yet it is clear that in order to make the formulations useful in empirical research considerably more work is required to develop indicators for different phases of the regime life-cycle or for the differing properties of niches, regimes and the landscape.

I would like to end this piece with a word of caution. Namely, while presenting the foregoing argument to different transitions scholars I have noticed an occasional but worrying tendency to contest the above claims mainly on metatheoretical grounds, e.g. through arguments that life-cycle perspective or variance theoretical approaches reduce the inherent richness and flexibility of MLP. The problem is not only that this argument often assumes a very particular definition of what these categories mean (see [114] for an example of a typology of theories of change that tries to draw a sharp contrast between life-cycle and evolutionary approaches, and [64, pp. 93-97] for similar juxtaposition of 'variance' and 'process' theory). The more serious issue with such metatheoretical shortcuts is that the arguments end up being discarded as 'ontologically inappropriate' before one can even start considering their usefulness for empirical research on the middle-range level. In other words, I sense a danger that various metatheoretical arguments once made by the proponents of MLP to clarify the positioning of the framework might increasingly start to function as blanket rhetorical devices for closing off certain research directions. It is also an early warning sign that the field of transitions research might be falling victim to its own emerging dogmas [52]. On pragmatic grounds I would therefore call for more middle-range heresies. After all, research on energy transitions will be truly advanced only by combining empirical rigour with theoretical imagination, including a healthy dose of scepticism about the *status quo*.

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