Transition 2.0 - New conceptual challenges for sustainability transition studies

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Abstract

As sustainability transitions progress over time, they pose new conceptual challenges for the frameworks we use. This paper starts with five such challenges from the ongoing energy transition. These include the interaction of multiple technologies, decline, intensified struggles among actors, sector performance, and cross-sector interaction. I discuss how two of the major frameworks in transition studies, the multi-level perspective and the technological innovation systems approach, can possibly deal with these challenges and what the implications are for improving our conceptual toolbox. The paper not only points to further research on how to address these new phenomena. It is also an invitation to reflect more intensely upon the phases of transitions.

Keywords: Sustainability transitions, multi-level perspective, technological innovation systems, conceptual challenges, energy transition

1 Introduction

Sustainability transitions are receiving a lot of attention in the field of innovation studies (Markard et al., 2012). Key frameworks such as the multi-level perspective, strategic niche management, or technological innovation systems have been used to explain innovation and transition dynamics in a broad range of cases and contexts (Bergek et al., 2008; Geels, 2002; Bergek et al., 2015; Schot and Geels, 2008; Smith and Raven, 2012). The frameworks have also been used to inform policy making in domains such as innovation policy and environmental policy (van den Bergh, 2013; Geels et al., 2017; Jacobsson and Bergek, 2011; Smith et al., 2010).

Since their inception, the original frameworks have been refined in a number of ways (e.g. Bergek et al., 2015; Geels, 2011; Papachristos et al., 2013; Smith and Raven, 2012). Nonetheless further amendments are needed. One reason for that is the following: We are currently entering a period, in which sustainability transitions gain traction. There is a shift from early stages of development with novel technologies emerging in niches into a phase of accelerated diffusion of multiple innovations with widespread, fundamental changes at the sectoral level (Markard, in press).

In the early years of a transition, researchers, firms and policy makers were primarily concerned with developing reliable technological alternatives, creating niche markets, forging networks and strategic alliances, and supporting industry formation (Dewald and Truffer, 2011; Jacobsson and Lauber, 2006; Musiolik et al., 2012). Studying these processes, transition researchers typically focused on a specific innovation (e.g. wind energy), identified barriers for further expansion and made policy suggestions of how to overcome these barriers (Bergek and Jacobsson, 2003; Geels and Raven, 2006; Negro and Hekkert, 2008). As a consequence, frameworks such as strategic niche management (Kemp et al., 1998; Schot and Geels, 2008) and technological innovation systems (Bergek et al., 2008; Hekkert and Negro, 2009; Markard et al., 2015), which focus on selected innovations and the associated dynamics, played a key role.

Meanwhile, some of the former niche technologies such as wind and solar have diffused widely and spawned mature industries with a high degree of professionalization, global value chains and technology providers operating internationally (GWEC, 2016; IEA, 2017b). At the same time, they have an increasing impact, e.g. as they compete with established technologies or change the interplay of technologies at the sector level (Markard et al., 2016b). As a consequence, new phenomena and policy issues arise. In the case of the energy transition, these include the system integration of renewables (Bird et al., 2013; Sinsel et al., submitted), multi-technology-interaction and complementarities (Markard and Hoffmann, 2016; Sandén and Hillman, 2011), a decline of established industries (Turnheim and Geels, 2013), global industry dynamics {Binz and Truffer, 2017} or the involvement of multiple sectors (Markard et al., 2016b; Sutherland et al., 2015).

I will argue in the following that the next phase of the transition brings new phenomena to the fore. Some of these phenomena challenge our established frameworks, which is why there is a need i) to identify the qualitative changes in the next phase of sustainability transitions, ii) to understand their conceptual implications, and iii) to make suggestions of how we can address these issues, e.g. by adapting existing frameworks.

The starting point of this paper is a recent discussion of the particularities of the new phase of the ongoing energy transition (Markard, in press). It highlighted four issues that challenge our frameworks: i) interaction of multiple-technologies (both emerging and mature), ii) technology decline, iii) escalating struggles among actors and iv) pervasiveness, i.e. dynamics that reach beyond the focal sector. Similarly, a recent paper on progress and challenges for the multi-level perspective argues that further conceptual elaborations are needed (Geels, 2018). These include i) interactions between niche innovations, ii) adoption of niche innovations and iii) interactions between multiple systems.

In the following, I briefly review the above challenges and discuss what implications they have for the conceptual frameworks we use. I concentrate on the multi-level perspective (MLP) and the technological innovation systems (TIS) approach as two prominent frameworks in the field.[1] In a third step, I review and add to existing suggestions of how the frameworks can be improved.

2 A brief introduction to sustainability transition studies

Transition studies are concerned with fundamental changes in sectors such as energy, transportation, food or water, which provide essential services for society (Markard et al., 2012; Smith et al., 2010). Theses transformations are multi-dimensional as they involve changes in technologies, business models, industry structures, policies and regulations, consumption practices and lifestyles. Many scholars in transition studies are concerned with sustainability challenges and there is a widely shared normative assumption that most established sectors *need to change* fundamentally in order to become more sustainable in the long run.

The term 'sustainability transitions' has been coined to refer to such purposive transitions: A *sustainability transition* is a set of long-term, fundamental transformation processes in a socio-technical system, or sector, associated with major sustainability challenges (Markard et al., 2012; Smith et al., 2010). Socio-

[1] Of course, the characteristics of the new phase of the energy transition can also be used to test the applicability of other frameworks.

technical systems consist of networks of actors (individuals, organizations, associations, NGOs, public authorities, policy makers), institutions (societal and technical norms, regulations, standards, policies) as well as technologies, material artifacts and infrastructures (Geels, 2004; Markard, 2011).

Transition scholars have provided numerous empirical accounts of historical and ongoing transitions and developed a series of conceptual frameworks to grapple with the complexity of transitions (Grin et al., 2010; Markard et al., 2012; Smith et al., 2010). The multi-level perspective and technological innovation systems are two prominent frameworks[2], which have been used widely to study the dynamics of energy transitions (Bergek and Jacobsson, 2003; Kern and Markard, 2016; Raven and Verbong, 2007; Truffer et al., 2012; Verbong and Geels, 2007; Wieczorek et al., 2015; Wirth and Markard, 2011).

2.1 Multi-level perspective

The goal of the *multi-level perspective* (MLP) is to explain the dynamics of transitions. Building on earlier work on socio-technical regimes (Rip and Kemp, 1998), it explains transitions by the interplay of dynamics on three different levels: niches, regimes, and landscape (Geels, 2002; Geels and Schot, 2007). Socio-technical regimes encompass established engineering practices, problem definitions, process technologies and dominant designs in a specific sector (e.g. electricity) that are socially embedded into the expectations and daily routines of technology users and supported by formal norms, regulations, and broader infrastructures (Kemp et al., 1998). The core idea behind a regime is that it is very resistant to change and imposes a direction for incremental socio-technical development along an established pathway. Niches are protected spaces, i.e., specific markets or application domains, in which radical innovations can develop without being subject to the selection pressure of the prevailing regime (Kemp et al., 1998; Smith and Raven, 2012). The landscape encompasses external factors and developments such as significant changes in commodity prices, major accidents and disasters, or long-term macro-economic or societal trends (Geels and Schot, 2007). According to the multi-level perspective, transitions occur if the landscape exerts pressure on the established regime and thus opens up opportunities for niche innovations to break through to the regime level and to eventually replace existing technologies and regime structures.

Scholars have applied the multi-level perspective to explain historic transitions such as the replacement of sailing ships by steam ships (Geels, 2002), the

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[2] See Markard and Truffer (2008) for a detailed introduction and review of the original concepts.

introduction of sewer systems (Geels, 2006) or the emergence and diffusion of the automobile (Geels, 2005). At the same time, the MLP has also been used to study contemporary phenomena such as the ongoing energy transition (Geels et al., 2016; Sutherland et al., 2015; Verbong and Geels, 2007).

2.2 Technological innovation systems

The *technological innovation system* (TIS) framework is used to study the emergence of a focal, novel technology together with the associated institutional and organizational changes (Bergek, Jacobsson et al. 2008; Carlsson and Stankiewicz 1991). The framework has emerged together with related innovation systems approaches such as national or sectoral innovation systems (Freeman 1988; Malerba 2002; Nelson 1988). A TIS has been defined as a network of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product (Markard and Truffer 2008). The concept emphasizes the close interplay of actors and institutions and suggests a set of seven key processes, so-called functions, for successful technology development (Bergek, Jacobsson et al. 2008; Hekkert, Suurs et al. 2007).

The TIS framework has received quite some attention for the analysis of emerging innovations and many TIS scholars have taken an interest in energy technologies (Truffer et al., 2012). Among others, researchers studied wind energy (Bento and Fontes, 2015; Wieczorek et al., 2015), photovoltaics (Dewald and Truffer, 2011; Quitzow, 2015), biogas (Markard et al., 2016b), smart grids (Erlinghagen and Markard, 2012), biofuels (Suurs and Hekkert, 2009) or fuel cells (Musiolik et al., 2012), typically in a specific national context.

2.3 Phases of transitions

This paper builds on the idea that transitions progress through different phases of development, which exhibit distinct characteristics. This is not new. Transition scholars have suggested early on, that socio-technical transitions can be conceptualized as a succession of different, ideal-type phases (Rotmans et al., 2001). Rotmans et al. (2001), for example, distinguish four phases: a predevelopment phase with no visible change, a take-off phase with first changes, a breakthrough with visible and profound structural changes along several dimensions (socio-cultural, economic, institutional), and a stabilization phase, in which changes slow down again. Many of the historical case studies on socio-technical transitions confirm both the long-term nature of transitions and different phases of 'progress' over time (e.g. Geels, 2005; Geels, 2006).

Similarly, the literature on industry life cycles has suggested different phases of industry development (Gort and Klepper, 1982; Klepper, 1997; Peltoniemi, 2011). The central assumption is that many industries show similarities as they evolve over time and that these common patterns are driven endogenously, e.g. by the shift from product to process innovation. Researchers have distinguished different phases of industry development, including an initial stage, several stages of rapid market growth, a shakeout stage, and a final or mature stage (Gort and Klepper, 1982; Gustafsson et al., 2016; Klepper, 1997; Taylor and Taylor, 2012). Emerging industries start with just a few actors, ill-defined products and a high level of uncertainty. This is followed by increasing firm entries, formation of networks, standards and value chains (Gustafsson et al., 2016). At some point sales take off, even more actors enter and a dominant design emerges, followed by a shakeout, decreasing market growth and stabilization.

2.4 Challenges and new phenomena in the breakthrough phase

For the following, I concentrate on five challenges to discuss the implications for existing transition frameworks. These include the i) interaction of multiple technologies in different stages of maturity (technology and system dimension), ii) decline of established technologies and business models (technology and organizational dimension), iii) escalating struggles between new and vested interests (organizational dimension), iv) importance of system functioning (system dimension), and v) the pervasiveness of the energy transition as it affects not just different parts of the electricity sector but also other sectors (technology and context dimension). Looking into these five issues is a pragmatic choice. They are not too many, cover different dimensions and challenge the transition frameworks. Future studies may want to look into other aspects and how they can be addressed theoretically.

2.4.1 Interaction of multiple technologies

In the formative phase of the energy transition, many novel technologies for power generation emerged, most of them based on renewable energy sources. In this phase, most novel technologies were immature with limited performance characteristics and high costs. As a consequence, they were supported by public policies and applied in pilot projects and niche applications (Negro and Hekkert, 2008; Raven, 2007). Existing technologies were not much affected by these developments.

In the new phase of the energy transition, some of the earlier niche technologies have matured substantially and diffused widely (see above). At the same time, a broad variety of complementary technologies and services have emerged in domains such as energy storage and system balancing (batteries, flywheels, compressed air storage), distribution and transmission (smart grids, demand side management) or multi-energy conversion (energy hubs, power-to-gas). Both, the new technologies in power generation as well as those in related domains, play a much stronger role than before. Existing technologies such as hydropower (generation & storage) but also fossil and nuclear generation are deeply affected (see below). As a consequence, we see multiple technologies in different stages of development and in different parts of the energy sector interacting. Interaction includes competition and complementarity as well as other types of relationships (Markard and Hoffmann, 2016).

2.4.2 Decline

In the early phase of transitions, decline does not play a role. Incumbent technologies and actors hold stable positions. In the second phase of the energy transition, we see decline becoming important. In many countries, the shares of established technologies such as nuclear or coal in power generation are going down. Germany saw a decline in nuclear power production from around 165 TWh/a in the early 2000s to 85 TWh/a in 2016 and in the UK coal decreased from around 130 TWh/a to 31 TWh/a in the same timespan (IEA, 2017a). These are major changes for electric utilities and those who invested in the respective power plants. Decline is often a consequence of substitution by other technologies such as renewable energies or natural gas in the case of the energy transition. In some countries, decline is accelerated by phase-out policies that target unwanted technologies. Examples include nuclear phase-out in Germany (Strunz, 2014), coal phase-out in Ontario (Rosenbloom, in press) or the ban of incandescent light bulbs in the EU and elsewhere (Stegmaier et al., 2014).

So far, decline has been primarily a phenomenon at national or regional levels. And while some countries phase-out specific technologies, others still use or even expand them.[3] However, as the sustainable energy transition progresses further, we can also expect decline happening at the global level. Such a development will be particularly relevant for internationally operating technology developers such as Siemens, ABB or GE. Global investments into new power generation capacity have already started shifting toward renewable energies. In 2016, global investments into renewables were twice as high as investments into gas and coal (UN and Bloomberg, 2017).

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[3] Especially India and China are still investing heavily in new coal-fired power plants.

2.4.3 Intensified struggles

The new phase of the energy transition is also characterized by more intense struggles between actors with conflicting interests. While incumbent actors could afford to ignore the formative phase, they are deeply affected by the ongoing developments, which represent a fundamental threat to their market positions and business models. Struggles of 'regime actors' and 'newcomers' have become fiercer and many organizations try to sway policy making through lobbying (Lauber and Jacobsson, 2016; Sühlsen and Hisschemöller, 2014).

As a consequence, the politics of transitions play a central role in the energy transition 2.0 phase. Advocacy coalitions are shifting as renewables become the new mainstream (Markard et al., 2016a), while fierce battles are fought over climate policies and renewable energy subsidies (Hess, 2014). At the same time, also firms in the new industries (e.g. producers of wind turbines or PV panels) are struggling as competition has intensified and shakeout processes are under way (Candelise et al., 2013). Interestingly, energy consumers are still not much affected. They were faced with changes in prices and some also became power producers ('prosumers') but consumption practices have remained largely unchanged.

2.4.4 System functioning and sector performance

In the early years, the impacts of intermittent renewable energies on the electricity grid and on the security of supply were rather negligible due to a low degree of diffusion. As wind and solar are diffusing widely, now they are. The expansion of photovoltaics in Germany, for example, had adverse effects on the economics of hydropower (Markard and Hoffmann, 2017). Moreover, many complementary technologies are developed to better predict, balance and store power generation by intermittent renewables (see above).

As a consequence, in the new phase the focus of policy making is shifting toward sector level performance and functioning. 'System integration' of renewables has become a central issue (Bird et al., 2013; Sinsel et al., submitted). Moreover, policy makers show an interest to control the pace of the transition and to ease adaptation for incumbent actors (Geels et al., 2016). In general, institutional changes are more pervasive than in the formative phase. Also electricity prices have become an issue of concern, especially in those cases where the costs for feed-in tariffs (or other subsidies) have to be borne by electricity consumers. In Germany, for example, this has led to heated debates and substantial changes in renewable support policies (Lauber and Jacobsson, 2016).

Interestingly, also in the second phase some basic principles and regime rules are still very stable. This includes the high relevance of 'security of supply' or the principle that power supply always has to meet demand. Also low energy prices are still a central mantra Lauber and Jacobsson, 2016.

2.4.5 Pervasiveness and cross-sector interactions

Pervasiveness has two elements. First, the energy transition spreads into parts of the sector that were not affected earlier. The transition spreads from innovations at the core (here: generation) to other layers of the larger system such as the grid or energy storage. An example is the case of distribution and transmission, where we see markets expanding and established technologies improving (Andersen and Markard, 2017).

Second, the energy transition increasingly affects other sectors, thereby triggering (or intensifying) cross-sectoral interaction. One example is agriculture, which saw quite strong competition for arable land in areas where biogas has diffused widely or biofuel production was ramped up (Markard et al., 2016b). Another example is transport, where electric vehicles are receiving a lot of attention given the premise that the electricity sector can provide sufficient amounts of 'clean' power (Markard and Hoffmann, 2017). A third example is heating and gas supply (Raven and Verbong, 2007). Both sectors already interact to a certain extent with electricity but these relationships are likely to increase as the energy transition progresses.

In summary, sustainability transition studies have received increasing attention not only for studying past but also ongoing transitions. The latter is particularly relevant for making policy suggestions of how to guide these complex transformation processes. Against this background, it is of central importance to keep up with the dynamics of transitions. As the ongoing energy transition progresses into a new phase of development, transition scholar have to revisit the existing conceptual framework and adapt them to the new empirical challenges. This is what I discuss next.

3 How the existing frameworks can deal with the challenges

This section concentrates on the multi-level perspective and the technological innovation systems approach. It discusses how both frameworks can deal with the five challenges.

3.1 Multi technology interaction

The original conceptualization of the multi-level perspective (Geels, 2002) and several historic case studies suggest that there is one dominant technology at the regime level (such as the sailing ship), which will eventually be replaced by one (out of many) successful niche innovations (such as the steamship). The situation in the second phase of the energy transition is more complex as there are several regime technologies for power generation (nuclear, coal, gas, hydro) and also a number of different niche[4] technologies (wind, biomass, PV), which compete but also complement each other (Markard and Hoffmann, 2016). As the 'classic' MLP does not capture this complexity right away, transition scholars have suggested to conceptualize and analyze multi-regime and multi-niche interactions in more detail (Papachristos et al., 2013; Raven, 2007; Verbong et al., 2007; xxx). In future research, it will be important to explore the complexity of these relationships further. This could include analyzing parasitic relationships such as a niche piggybacking[5] a regime technology (PV and hydro), or further differentiating the roles different actors play as they engage both in 'niche' and 'regime' activities (Berggren et al., 2015).

Table 1: Energy transition 2.0 – key challenges for transition frameworks

	Multi-level Perspective	Technological Innovation Systems
Multi-technology interaction	Better conceptualization needed, including complementarities or piggybacking; competition of "regimes-to-be"	Focus on single technology problematic; other technologies can be conceptualized as TIS context; tech-principles not yet addressed
Decline	Further theorizing required: processes, extent, policies.	First conceptual suggestions. Can possibly be integrated into the framework. Further empirical studies needed.
Intensified struggles	Incorporates struggle; struggle of regime vs. niche actors too simplistic; missing complexity of actor roles and politics	Tendency to emphasize collaboration of actors rather than competition and conflicts; problem to integrate struggles into TIS functions
System functioning	Challenge: Functioning of new system not in the focus.	Major challenge: Functions focus at the technology level. Sector level not part of the framework.
Pervasiveness / cross-sector interaction	Original framework focuses on one regime/sector. Later work has elaborated on multi-regime dynamics	Major challenge for the TIS framework.

Another conceptual challenge is that some technologies have certain (inherent) characteristics (e.g. whether they are dispatchable or intermittent) that require specific complementary technologies or institutions to support them. These can

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[4] Wind, biomass and PV have clearly surpassed the 'niche'-state in many places. The label is used here to discern new from established technologies.

[5] A niche technology might compete with but benefit from the existence of a regime technology at the same time. Such kinds of interactions as well as complementarities are still under-conceptualized in the MLP.

be thought of as 'regime-to-be', i.e. emerging, interrelated structures that fulfill a specific function. As a consequence, a transition may not just be about the competition between specific technologies but between different regime-configurations.

Also for the TIS framework, multi-technology interaction represents a challenge. The approach has been designed to concentrate on a single technology, or a larger technological field (Bergek et al., 2008). So far, TIS scholars have addressed multi-technology interaction by placing other relevant technologies in the TIS context, i.e. translating technology interaction into TIS-TIS interaction (Bergek et al., 2015; Wirth and Markard, 2011). Where these interactions are strong and central for the overall dynamic of a transition (Sandén and Hillman, 2011), further conceptual work is needed, e.g. to specify how TIS-TIS interaction can be captured with an analysis of TIS functions.

3.2 Decline

While a decline of incumbent technologies and a destabilization of regime structures is at the core of the MLP, more theorizing is needed on how such a decline unfolds over time (Turnheim and Geels, 2012), e.g. how far it goes[6], what typical decline processes are, who survives, or how to accompany or accelerate it by public policies. The new phase of the energy transition also holds interesting puzzles for regime destabilization, as some regime rules are still very stable (Fuenfschilling and Truffer, 2015). In terms of regime transformation, research on transition pathways is certainly a promising line of research (Berggren et al., 2015; Geels and Schot, 2007; Geels et al., 2016) and also recent studies on industry decline and regime destabilization may provide key building blocks to further advance the MLP (Karltorp and Sanden, 2012; Turnheim and Geels, 2012).

Within the TIS framework, there is a large gap to fill with technology decline. Researchers have just started to engage with the topic, including suggestions for processes (functions) that stimulate decline (Kivimaa and Kern, 2016) or a TIS lifecycle framework (Markard, under review). However, there is little to no empirical work on this, which is why further studies in the context of the new phase of the energy transition are certainly warranted.

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[6] I.e. whether it encompasses just some or all regime dimensions (technologies, policies, organizations, norms, practices), whether they change all at once or in sequences etc.

3.3 Intensified struggles

The struggle of incumbent regime actors against newcomers operating at the niche level is at the core of the MLP. Accordingly, an escalation of this struggle seems to be very much in line with what the framework suggests. However, MLP based research can still pay more attention to the role of politics, e.g. energy incumbents influencing policies in order to slow down the pace of the transition, or to change its pathway (Geels, 2014; Smink et al., 2015). Moreover, regime actors have been observed to innovate both in relation to established as well as novel and potentially disruptive technologies (Bergek et al., 2013; Berggren et al., 2015). For example, we find both incumbent utilities as well as new entrants investing in wind energy. So the traditional niche-regime dichotomy needs to be differentiated as research on the roles of different actors accumulates.

Struggles between competing actors and technologies are a conceptual challenge for the TIS framework. So far, most TIS studies have focused on (a variety of) actors that *support* the focal technology, e.g. as they *collaborate* in networks or alliances to improve TIS structures and system resources (Dewald and Truffer, 2012; Konrad et al., 2012; Musiolik et al., 2012). Actors and activities that *work against* the focal technology are typically not in the focus of TIS scholars. Conceptually, resistance is typically assigned to the TIS context, which creates a challenge when they are central for certain developments. As a consequence, scholars will have to revisit the understanding of TIS actors and to conceptualize battles over system structures in addition to system building (e.g. M&E 2017).

3.4 System functioning and sector performance

The flipside of regime destabilization is the formation of new regime structures at the sectoral level, which have repercussions for how the overall function of the socio-technical system (here: power supply) is fulfilled. Such 'system functioning' in the course of a transition is an issue that requires more attention. The MLP assumes stable (and functioning) regimes at the beginning and end of transition but has less to say about *system performance during the transition*, especially as central regime rules change.

TIS scholars are used to analyzing system performance at the technology level. As there are major differences and potentially even trade-offs between technology and sector level performance (Markard and Hoffmann, 2016), new tools would be required to analyze sector performance. The TIS functions framework may provide inspiration in this but the endeavor will very much go beyond the existing TIS framework.

3.5 Pervasiveness and cross-sector interaction

In its original version, the MLP is rather quiet about cross-sectoral impacts. Dynamics in other sectors are usually assigned to the landscape level. This is why scholars have studied and conceptualized ‘multi-regime interactions’ of two ore more regimes /sectors (Konrad et al., 2008; Papachristos et al., 2013; Raven and Verbong, 2007; Sutherland et al., 2015). For the case of the energy transition, more insights are needed into how these multi-regime interactions unfold (intensify, weaken, accelerate, slow down). Also, there is a need for more empirical studies on the various processes and relationships underlying multi-regime interaction. Another aspect of pervasiveness is that the energy transition involves more and more layers of the energy sector (transmission, storage, consumption) as it unfolds. Such ‘successive regime shifts’ still need to be conceptualized within the MLP framework.

In TIS research, the issue of cross-sector interaction has been taken up in some (e.g. Markard et al., 2016b; Wirth and Markard, 2011) but it is less visible in the framework itself. Given the new conceptualization of TIS context, the framework enables studies that analyze the impact of developments in different sectors on the focal technology and vice versa (Bergek et al., 2015). Whether this can be a starting point to also look into entire transitions affecting other sectors, remains to be seen.

3.6 Summary

In summary, the MLP is challenged by many of the issues emerging from the new phase of the energy transition. This holds in particular for its original conceptualization and the niche-regime dichotomy. It has proven very successful in the early years of transitions (explaining why niches have such a hard time and regimes are so stable) but might become somewhat of a cognitive restraint in subsequence phases. The analysis also shows that MLP scholars have already started to address several of the above issues. It seems that none of the six challenges is per se incompatible with the core concepts and assumptions of the MLP.

With regard to the TIS framework, the assessment reveals that the approach is very much challenged by energy transition 2.0 phenomena. It has proven to be very successful in the first phase but these strengths may even turn into weaknesses given the current line of developments. One obstacle is that the TIS was not designed as a transitions framework. As a consequence, it lacks central elements (such as a regime or sector concept), which would allow addressing sector level challenges. It seems that the TIS framework can analyze some transition 2.0 phenomena (e.g. decline, multi-tech interaction) but not all of them. The latter would probably require an approach, which combines TIS and MLP elements (Markard and Truffer, 2008).

4 Conclusions

Research in the field of sustainability transitions has gained quite some traction in recent years and scholars have also made many suggestions of how to improve existing frameworks. At the same time though, there is increasing evidence that new phenomena come to the fore as socio-technical transitions progress over time, and that some of these phenomena pose quite substantial challenges for the concepts we use. The paper has drawn on the example of the ongoing energy transition to illustrate some of these challenges. In several places, the energy transition has entered a new phase of development that is characterized by the interaction of multiple technologies, decline, escalating struggles among actors, an increasing importance of system functioning, and an extension of the scope of the transition (pervasiveness).

These phenomena pose new challenges for businesses, policy makers and transitions scholars. Focusing on the latter the paper has shown that both MLP and TIS have several shortcomings when it comes to the current phase of the energy transition. They are not (yet) sufficiently equipped to deal with multi-lateral struggles and politics, the increasing importance of sector level functioning, or the complexity of the multiplicity of technology (and non-tech) interactions that come to the fore when a transition takes off.

As a consequence, further conceptual work will be needed. This includes an explicit integration of recent conceptual suggestions such as the work on multiple modes and levels of technology and niche-regime interaction (Papachristos et al., 2013; Sandén and Hillman, 2011), technology and non-technology complementarities (Markard and Hoffmann, 2016) or technology and industry decline (Kivimaa and Kern, 2016; Turnheim and Geels, 2012).

As we embark on the journey to improve the existing frameworks, we have to keep in mind that many more challenges lie ahead. First, there will be more phenomena in the second phase of sustainability transition than those above. Second, there will be substantial variation across sectors and countries. Third, there will be additional challenges in a third phase and beyond.

Ad 1: It is important to note that there will be more challenging phenomena in the new phase of sustainability transitions. One reason for that is that we still have limited experiences with the case of the energy transition: So far, just some countries have progressed substantially. Another reason is that some phenomena are closely related to intermittent power generation, which means that we might see different effects for energy transitions that build on other generation technologies. More importantly even, there may well be more and different phenomena if we turn to other sectors (e.g. transportation, food). For example in the food sector, technology issues and system level complementarities may play somewhat less of a role than in electricity, while consumer issues, (eating) habits and lifestyles are more important when studying transitions.

Ad 2: We also have to keep in mind that not just sectoral but also spatial variations occur. Scholars have highlighted time and again that transitions unfold very differently in different places (Binz et al., 2014; Coenen et al., 2012). For example, Geels et al. (2016) identify a more disruptive, decentralized energy transition pathway in Germany, while the energy transition in the UK represents much less of a threat for incumbent firms as centralized power sources remain dominant and many established business models prevail. The broader issue here is that different institutional contexts affect how transitions unfold (Bergek et al., 2015; Geels and Schot, 2007; Wirth et al., 2013). As a consequence, we cannot expect that all of the six aspects identified above are equally important in every energy transition case.

At the same time, the pervasiveness of the energy transition 2.0 has a technological and institutional dimension that tends to reduce contextual differences over time. Technologies such as solar or batteries diffuse globally (and partly even across sectors) and also institutional structures (e.g. policies, expectations, market designs, standards) may be transferred to new places.

Ad 3: We will certainly encounter new phenomena as the energy transition progresses even further into a third phase (and beyond). In the case of electricity, the changing role of consumers and changes in consumption practices may receive more attention in the future. Up to know, consumers have not changed their consumption practices at all. Also, private consumers have been very reluctant to even switch electricity suppliers. In other words, the consumption side has not played much of a role in the first two phases of the energy transition. This explains why transition studies sometimes seem to be myopic when it comes to consumer practices and lifestyle issues (Shove and Walker, 2007; Shove and Walker, 2010). As the energy transition unfolds further we might see more change in this dimension and possibly also frameworks being more susceptible to the 'consumption side'.

Finally, it is also interesting that there are some regime rules (or principles), which have remained very stable, even in the second phase of the transition. These include the importance of security of supply, the principle that supply always follows demand and that electricity has to be cheap. These principles have emerged over decades and some (e.g. the importance of low prices) were even strengthened quire recently with the introduction of market liberalization. Such phenomena shed new light on the disruption dynamics of regime structures. While the MLP suggests that, at some point, all dimensions of the regime destabilize and break up, the case of the energy transition seems to suggest that some principles do change while others – at least until now – remain very stable. Further research is certainly warranted here.

To conclude, the ongoing energy transition is revealing many phenomena, which not only question some of the basic assumptions of the established conceptual frameworks but also show that there is often a higher degree of complexity, interaction and variation than our existing models suggest. The energy transition 2.0 comes with a new level of challenges. It invites us to develop new perspectives and adapt existing approaches. This paper has proposed some first steps along this way.

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