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DOI
10.4324/9780429056574-7

Publication date
2019

Document Version
Final published version

Published in
Modelling Transitions

Citation (APA)
Holtz, G., & Chappin, E. (2019). Considering actor behaviour: agent-based modelling of transitions. In E. A. Moallemi, & F. J. de Haan (Eds.), *Modelling Transitions: Virtues, Vices, Visions of the Future* (1 ed., pp. 102-118). (Routledge Studies in Sustainability Transitions). Routledge - Taylor & Francis Group. https://doi.org/10.4324/9780429056574-7

Chapter 7 in: Modelling Transitions: Virtues, Vices, Visions of the Future. Enayat A. Moallemi, Fjalar J. de Haan (eds.). Routledge Studies in Sustainability Transitions. Routledge London & New York, 2019

Considering actor behaviour: agent-based modelling of transitions

Georg Holtz and Émile J.L. Chappin

Abstract
Transitions emerge as outcome of the decisions, behaviours and interactions of a multitude of actors operating in a changing institutional context. Agent-based modelling (ABM) allows for the representation of heterogeneous actors and their interactions, and to let system level dynamics emerge. In this chapter, the authors provide a brief introduction to ABM, investigate the conceptualization of actors and institutions in the transition research field, and the challenges for ABM of transitions that arise from the multitude of actors and institutions as well as from the diversity of theoretical perspectives to describe them. Four approaches to tackle these challenges are discussed.

1. Introduction

A transition is a fundamental shift in a socio-technical system such as the energy, mobility or food system that emerges from co-evolutionary developments in the social, technical, political, regulatory, and market domains. Transitions are large scale processes that span up to several decades and take place across nested spatial levels ranging from the local to the global levels. It is a widely shared conviction of transition researchers, that transitions are open, path-dependent processes with uncertain outcomes, and not pre-determined (e.g. by technological determinants). That is, transitions essentially are driven by and emerge from actors' decisions, behaviours and interactions, whereas the pace and direction of transitions are beyond the control of single actors or small actor groups. Furthermore, a broad range of institutions[1] permeate socio-technical systems and form the (changing) context in which those actors act.

Boxes 1 and 2 illustrate the broad range of actors and institutions involved in a transition, using the example of the transition of the German electricity system towards a mostly renewables based electricity system.[2] They are not only power producing companies, but

[1] The term 'institutions' is used here in its sociological meaning. In the institutional school of thought, there is, however, no universally agreed definition of the term. We use it to broadly refer to formal and informal rules and regulations that structure and give meaning to social life.

[2] We use this example of a transition for illustration of our arguments because we are particularly knowledgeable about it. However, we propose that the points made in this chapter

technology developers, grid operators, large and small consumers (and prosumers), policy makers, regulators, traders, etc. All of those actors take decisions from their respective perspectives, and their behaviours are driven by their particular interests and motivations. They operate in many markets (various electricity markets, fuel markets, emission markets) which are governed by a complex institutional context that provides frames for actors' perspectives, and guides and constrains their behaviours. Furthermore, systems are strongly interconnected (electricity being a backbone for other infrastructures and services) and span national borders, which leads to cross-policy and cross-border effects (Chappin et al. 2017).

Box 1: Actors in the German electricity transition

To give a non-exhaustive list, the German electricity system is governed and operated by the following actors: big utility companies operating mostly large-scale electricity production plants; small-scale plant owners including private households, farmers and cooperatives; regional supply companies; municipality utilities; a variety of consumer types ranging from private households to large industrial consumers; transmission grid operators; distribution grid operators; specific actor groups who operate at electricity markets and the interface between markets and the physical system, such as electricity brokers, balancing group managers and aggregators; power plant producers, craftsmen and technicians; the grid regulator; legislators and executive authorities on local, regional, national and European levels; capital suppliers; insurance firms; a variety of associations representing different interest groups; NGOs; community level initiatives; research institutes and universities. The apparent need for deeper integration of different energy sectors – in particular integration of the electricity sector with the heat, mobility and industry sectors – further increases the range of actors and (diverging) interests that shape the electricity system.

From this perspective, a 'transition' may emerge as an outcome of the decisions, behaviours and interactions of the multitude of actors involved. A better understanding of the emergent dynamics that result from the interactions of those actors with their respective powers and interests in the specific institutional context would not only be of scientific interest, but support the steering of transitions towards vital societal goals for maintaining and increasing societal welfare in the coming decades.

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about the multitude of actors and institutions and the diversity of theoretical perspectives for describing them are not limited to this particular transition.

Box 2: Institutions in the German electricity transition

Using the classification of Scott (2001) and following up on the example of the German electricity transition, institutions include *regulative institutions*, examples of which are: technical standards for power generation units, grid operation and appliances; market access and market clearance rules for the different electricity markets; regulations and procedures that safeguard grid stability, such as re-dispatch of power plants and provision and utilization of balancing energy; and taxes, fees and subsidies (e.g. feed-in tariff) that shape the economic calculations of providers and consumers. *Normative institutions* are less 'hard coded', but influence actors' behaviour as their behaviour is subject to scrutiny by others who hold particular expectations about those behaviours. Examples include investors and companies' expectations about capital return rates for investments; engineers' rules of 'good practice'; and behavioural norms such as to turn off the light when leaving a room. Last, but not least, *cultural-cognitive institutions*, covering the 'taken-for-granted' common beliefs and shared understanding that create frames through which meaning is made, shape actors' behaviour in more subtle yet fundamental ways. Examples include: provision of electricity always follows demand[1]; nuclear power will be phased out and renewables will form the core of a future sustainable electricity system; electricity is a marketable good; and other guiding principles such as a liberalized market.

Agent-based modelling (ABM) is a modelling method whose particular strength is representing heterogeneous actors and their interactions, and letting system wide structures and dynamics emerge from those actors' interactions. Behaviours of actors are represented through 'decision rules', whose designs are flexible. A rich set of modelling practices has emerged and this provides for the possibility to represent a diversity of decision-making modes and rich institutional contexts. The strength of ABM – simulating heterogeneous agents making decisions and interacting with each other – fits well with the understanding of transitions as emerging from the interactions of heterogeneous actors in an institutional context. This makes ABM a key approach to modelling transitions.

The abundance of different actors and institutions shaping the transition process and the multitude of theoretical perspectives for describing and understanding them, however, poses considerable challenges to the design of agent-based models.

In this chapter, we provide a brief introduction to ABM, investigate the conceptualization of actors and institutions involved in transitions, the challenges that arise from their multitude for agent-based modelling of transitions, and discuss four different approaches to tackle these challenges. We point out examples for each approach.

2. Agent-based modelling

ABM allows for the study of complex systems from a bottom-up perspective and has been applied in a broad range of disciplines, ranging from molecular self-assembly, biology and ecology to economics, sociology, anthropology, and cognitive science (Macal and North 2010). Agent-based models define elements – the agents – that interact with each other and their environment. Agents thereby may be heterogeneous in their attributes and behavioural rules. When applied to social systems, at their core, agent-based models consist of agents that represent actors that interact with each other and their environment. Simulation of agents' interactions over time then allows for generating emergent phenomena on the level of a group, organisation or other collection of actors – be they spatial or temporal patterns or characteristic statistical distributions of variables of interest – based on the boundedly rational behaviour and social interactions of these actors (Gilbert and Troitzsch 2005; Heckbert, Baynes and Reeson 2010).

As such, ABM provides a means to identify possible explanations for emergent system-level behaviour by identifying underlying mechanisms, i.e., by providing a causal reconstruction of the processes that account for the emergent phenomenon (Epstein and Axtell 1996), and hence to enhance understanding of system behaviour. Furthermore, agent-based models are also a promising approach for policy support (Chappin 2011; Farmer and Foley 2009). As Bankes (2002) justifies, ABM can be used for policy support because of (i) the unsuitability of competing modelling formalisms to address the problems of social science, (ii) agents as a natural ontology for many social problems, and (iii) its power to demonstrate emergent phenomena, i.e. to relate actors' behaviours and system level developments. Besides understanding and policy support, ABM can be used for other purposes, such as developing an explicit and systematic description of a complex socio-technical system. Different purposes come with different challenges and data needs. It is, however, beyond the scope of this chapter to discuss those in detail.

The ABM method does not impose any restrictions concerning the level of abstraction of the analysis. It is suitable for modelling a particular case in great detail, as well as for developing a model that abstracts from a wide range of empirical phenomena that share some common features (Boero and Squazzoni 2005; Sun et al. 2016). Furthermore, agent-based models can be developed for a variety of empirical scales, ranging from small groups up to the supra-national level. ABM is therefore applicable to a broad range of research questions that relate to various empirical scales. Concerning the modelling guideline, that model design should follow the model's purpose, it can be observed that the flexibility of the ABM method facilitates a vast range of model designs, i.e. the method does not per se impose strong limitations to tailoring the model to fulfil a specific purpose. There are, however, delicate interdependencies between a model's purpose, it's design and resulting complexity, data availability, and validity.

We conclude that, in principle, ABM is well suited for developing a bottom-up representation of a transition, and in particular for the representation of social aspects (heterogeneous actors, various types of decisions) that are more difficult to grasp with other modelling methods (Hoekstra, Steinbuch, and Verbong 2017). Furthermore, ABM allows studying the co-evolution of technical and social elements of a system, and facilitates to trace back transition dynamics to actors and their interactions.

3. Conceptualization of actors in transitions

An essential step for agent-based modelling of transitions is to define agents, based on a selection of the real-world social entities they shall represent. Often, and most intuitively, agents represent actors. This section therefore provides a brief overview of the knowledge base modellers can draw on for selecting and describing actors involved in transitions.

In the social sciences, actors have been studied and described on different levels of aggregation, ranging from individuals, corporate actors (e.g. organizations, firms) to collective actors (e.g. consumer types). Individual actors have been discussed as playing a role in transitions for example as 'frontrunner', 'change agent', 'champion' or 'policy entrepreneur'. Corporate actors include a set of individuals who are linked in an organizational structure and through organizational routines, and jointly act according to the goals and interests of the organization. For understanding their role in transitions, organizations can often be treated as one single (corporate) actor. Organizations involved in transition processes include public authorities, firms, social movements or research organisations. Collective actors cover larger numbers of individuals in similar roles that act and interact in an unorganized way (e.g. consumers in a market). Their behaviours sometimes can be simply aggregated. However caution needs to be applied because their interactions can also lead to non-linear system level dynamics – for example if network effects lead to a self-reinforcing diffusion of an innovation.

Actors can also be distinguished through the differentiation of categories or backgrounds to which those actors belong – such as policymakers, firms, users, social movements or civil society. Actors belonging to different categories most likely differ in their perspectives, powers, interests, etc. They have different behavioural options and furthermore are influenced by their respective institutional contexts (see below). Furthermore, actors can assume multiple roles in the transition, for example Schot, Kanger and Verbong (2016) distinguish five roles of users (user-producers, user-legitimators, user-intermediaries, user-citizens and user-consumers). Each role reflects a different type of action on the system. Given this diversity, describing and understanding actors and their behaviours requires sensitivity to their particular characteristics and context. The social sciences, including the different strands of economics, (social-)psychology and sociology provide a wide range of concepts and theories, including for example: utility, preferences, values, interests, cognitive frames, expectations, routines, social practices, norm following behaviour, heuristics, strategies, power, and learning.[3] For modelling actors belonging to different categories who assume particular roles, one should carefully reflect on the selection of appropriate theories of decision-making and behaviour.

To support this reflection and selection, a clear conceptualization of actors and their behaviours in the context of transitions would be a valuable starting point for agent-based modelling of transitions. Such a conceptualization – that maps the 'jungle' of possibilities and provides insights into which actor theories are most suitable for the representation of which

[3] Jackson (2005) provides an excellent overview that provides an introduction to a wide range of theories.

type of actor in which role, and for understanding their behaviours in the context of transitions – could support the modeller and give orientation when taking decisions about a selection of actors, an appropriate level of aggregation, and most appropriate variables and processes for describing their behaviours.

However, developing a systematic account of the actors involved in transitions is challenging due to the diversity of sectors and countries / regions analysed by transition researchers, which exhibit partly idiosyncratic sets of actors and institutions. Conceptualising actors and their interactions has only recently begun in transitions research, and different perspectives have been taken to systematize actors.

Fischer and Newig (2016) conduct a comprehensive review on the treatment of actors and agency in transitions research. They find that the often stated hypothesis that actors have been neglected in favour of more abstract system concepts cannot be confirmed on a general level. Rather, they find a diversity of approaches to classify actors and identify different typologies to group actors involved in transitions: actors related to the levels of the multi-level perspective[4], actors related to institutional domains (e.g. government, market, civil society), and actors related to levels of governance (local, regional, national, global). They furthermore discuss intermediaries as a specific class of actors, because some scholars see them as important actors for information distribution and mediation during a transition.

Avelino and Wittmayer (2016) observe that most contributions in transition studies which refer to actors are troubled by conceptual ambiguity. They develop a conceptualization of actors who exercise power in transitions and their shifting power relations. They distinguish between four categories of actors (state, market, community and third sector) along three axes (informal – formal, for profit – non profit, public – private) that imply different 'logics' of the respective sectors. They furthermore distinguish between actors at different levels of aggregation (individual actors, organizational actors and sector level actors) to facilitate different framings ranging from perceiving a sector (e.g. 'the state') as one actor to seeing those sectors as sites in which more specific individual and organizational actors interact.

Wittmayer et al. (2017) argue that the transitions literature does not attend to the fact that social roles can themselves be changing during a transition, and that transitions research to date even "lacks a suitable vocabulary to analyse the (changing) interactions and relations of actors as part of a sustainability transition" (p.46). They propose the concept of 'roles' to study changes in the social fabric and of shared values, norms and beliefs.

de Haan and Rotmans (2018) develop a theoretical transitions framework that includes a conceptualisation of actors and agency as one of its three main pillars. Actors are perceived as being value-driven, and a typology of four different transformative actor roles ('frontrunners', 'connectors', 'topplers' and 'supporters') is proposed. Those actors are suggested to be in the

[4] The multi-level perspective (Geels et al. 2017; Rip and Kemp 1998) is a widely adopted framework to analyse transitions.

centre of three different types of 'alliances' ('initiatives', 'networks', 'movements') between actors.

We conclude that a huge wealth of concepts from the wider social sciences is available that developers of agent-based models of transitions can draw on, but that the narrower field of transitions research (so far) provides no widely agreed conceptualization of actors that would provide guidance and orientation for the selection of most appropriate concepts and theories for modelling actors in the context of transitions. Different in-roads to conceptualize actors in transitions have, however, been made by some scholars, which could serve as starting points for developing agent-based models.

4. Conceptualization of institutions in transitions

A core observation and theoretical pillar of transition research is that the established dominant system shows inertia to radical change and rather follows a path of incremental changes. Besides factors such as vested interests, sunk investments and longevity of some technical artefacts and infrastructures, a main source for this inertia is seen in the institutions that govern the perceptions and behaviours of actors.

The theoretical development of the role of institutions in transition research as condensed in the multi-level perspective draws on insights from evolutionary economics and enriches those based on institutional theory as well as Giddens' structuration theory (Fünfschilling 2014). The core concept of the 'regime' originated in evolutionary economics, where the 'technological regime' or 'technological paradigm' referred to shared cognitive routines – such as common beliefs and assumptions amongst engineers about which technological advances to pursue and certain sets of problem solving activities of firms – that result in an innovation process that follows an internal logic and streamlines innovation efforts along certain pathways (Nelson and Winter 1985; Dosi 1982). This breaks with neo-classical assumptions about rational actors as well as simple supply and demand dynamics. Instead, institutional structures – in this case cognitive routines – become highly responsible for the evolution of technological innovation.

This conceptualization has been widened in subsequent work by transition scholars, in particular the field of relevant actors has been broadened to encompass not only engineers and firms, but also policy makers, users, associations and other actors. All of these actor groups are seen as being guided by their own set of institutions, or 'regimes'. Building on Scott (2001), Geels (2004) goes on to widen the focus on cognitive routines of early evolutionary economic work and to distinguish between regulative, normative and cognitive institutions, which provide different kinds of coordination and structuration of the activities of the different actor groups (see Box 2 for examples). The *regulative* dimension refers to explicit formal rules, which constrain or provide incentives to particular behaviours, and which are backed legally (e.g. taxes, trade laws, patent laws). The *normative* dimension covers rules whose basis of compliance is social obligation and which follow the logic of 'how we do things' (e.g. role expectations). *Cognitive* institutions provide the frames through which meaning is made, which are often taken for granted and culturally supported (e.g. concepts, beliefs, jargon/language). Relating those different types of institutions to the different actor domains results in a matrix that classifies a multitude of specific institutional domains (e.g. formal rules in markets; normative rules in the policy regime) that can be ascribed a certain relevance for understanding transitions, and to whose elaboration different literatures (e.g. sociology of technology, innovation studies, cultural studies) contribute.

The overarching 'socio-technical regime', that lies at the heart of transition studies, provides some meta-coordination to the development of this diversity of institutions (Geels 2004). The reason for this is that institutions are linked to each other, forming rule systems, not only within each actor-group related regime, but also between those regimes.

Overall, empirical and conceptual work on transitions emphasizes the importance of institutions for understanding transitions. Geels (2004) provides a classification scheme that crosses societal domains with three different types of institutions which is useful as a starting point to provide orientation and overview of the many areas in which institutions become relevant in transitions. For specific conceptualizations of the institutions in those areas, the modeller must refer to scholars from different literatures. More recent work (e.g. Fünfschilling 2014) elaborates on the understanding of the dynamics of institutional structures over time.

5. Challenges for modelling transitions with ABM

As outlined above, ABM opens a range of unique possibilities for representing heterogeneous, bounded-rational actors[5], and thus for the relaxation of certain fundamental assumptions regarding the optimality of actor behaviour that underlie other types of models, in particular optimization models. The strength of ABM to allow for relaxation of fundamental assumptions often is a source for criticism at the same time. While other modelling methods have fewer degrees of freedom, their implicit assumptions are widely shared and typically not challenged time and again for each newly developed model. In contrast, agent-based models vary greatly in their selection and representation of actors and institutions. Each newly developed model may be criticized for the specific assumptions on which it relies, because due to the fragmented and qualitative insight base from the social sciences, those assumptions could typically also be made in a different way. A core challenge for agent-based modelling in all types of fields therefore is to underpin the 'correctness' or usefulness of a model.

Agent-based modelling research started with abstract models to showcase and explore fundamental principles (e.g. Epstein and Axtell 1996). Since then it has increasingly been

[5] The rational actor is assumed to identify all possible behaviours, to determine all consequences for each possibility, to evaluate all those consequences, and then to choose the solution that optimizes utility. Real actors face uncertainty about the future, have limited access to information and may have limited resources and cognitive ability for determining and evaluating consequences. Due to these reasons, fully rational decision making is not possible in practice. Simon (1957) proposed the term 'bounded-rationality' to highlight the limitations of practical decision making.

recognized that empirical embeddedness of agent-based models – i.e., calibration and validation of models based on empirical data – matters for drawing policy relevant conclusions. Traditionally, validation is understood as testing whether the model captures reality sufficiently well through comparison of the model and its results with empirical data (Windrum, Fagiolo and Moneta 2007). This includes demonstrating the correspondence between model entities and processes that constitute the micro-foundation of the model with real-world entities and processes. It furthermore includes demonstration of the ability of the model to replicate emergent empirical patterns on the system level. Conventional validation is, however, often challenging for ABM.[6] Degrees of freedom for designing agent-based models are large, and theoretical and empirical knowledge to guide model design is often limited when it comes to specific details of the model design. A certain level of subjectivity with regards to the model structure chosen by the model builder therefore is unavoidable for ABM. A lack of empirical data to test and parameterize the model often results in a number of alternative plausible model structures and free parameters.

Those challenges for the design and validation of agent-based models are very pronounced when modelling transitions at full scope. In particular – as outlined in the previous sections – there are many different actors and institutions involved in transitions, resulting in a vast number of possibilities for the selection of actors and institutions and their formal representation. Transition research does not provide much guidance for this task. Furthermore, data for rigorous testing of alternative model designs is typically very limited or not available at all. In particular, transitions typically feature such a level of idiosyncrasy that system level data is required to parameterize the model for this particular transition, and no data is left for rigorous validation (e.g. Bergman et al. 2008).

Based on our discussion so far, we argue that transitions – understood in the meaning and wide scope adopted in this book and including the multiplicity of involved actors and institutions outlined above – include too many different actors and institutions for explicitly representing *all* of them at a great level of detail into a model with a reasonable level of complexity. Some strategy for the selection and abstraction of actors and institutions to be represented in agent-based models is needed. Based on examples from the literature and our own experience in the field, we have identified four different strategies for the selection and formalization of actors, their behaviours, and of the institutions guiding actor behaviour. We discuss those in the next section.

6. Modelling strategies

Against the background of the multitude of actors and institutions shaping transitions, we discuss in the following four strategies for dealing with the resulting challenges, based on examples from the literature. The first three strategies focus on the identification of a useful

[6] It is beyond the scope of this chapter to discuss challenges and approaches for traditional model validation and alternative approaches to validation at greater length, in particular as those are strongly linked not only to the model design but also the model purpose. The interested reader is referred to Moss (2008).

sub-system that facilitates reduction of the model's scope. This simplifies a selection of actors and institutions. The fourth strategy aims at abstraction from individual actors and institutions.

6.1 Focus on sub-problems

This first strategy includes definition of a sub-system of smaller scope that is suitable for capturing a relevant sub-process of the overall transition. This means the resulting model refrains from trying to capture the transition in its full scope, but reduces the scope in terms of temporal or spatial scale, topic, or otherwise; often using a suitable combination of dimensions in which the focus is narrowed. The narrower focus then allows making a selection of actors and institutions to be included in the model, leading to a model of manageable complexity.

For example, Friege et al. (Friege, Holtz and Chappin 2016; Friege 2016) focus on a particular sub-topic of the energy transition, namely the insulation of buildings. The rationale of this focus is that improving the energy efficiency of buildings through increasing the insulation rate of the existing building stock is vital for a success of the German energy transition, and that this sub-problem shows persisting inertia to existing policy interventions (such as providing financial incentives). Besides a reduced topical focus, the model furthermore limits its scope to a city, based on the reasoning that relevant interactions among actors take place on this scale, while national policies can still be included as external influences. On the temporal scale, the model runs are limited to a time span of ten years, which was found to be a sufficiently long time span to capture relevant aspects of the target system, such as the age distribution of buildings. At the same time, the time frame is short enough to reasonably abstract from co-evolutionary developments with other parts of the energy system. In sum, the model reduces its scope in terms of topic, spatial scale and temporal scale to achieve a well-defined sub-problem.

In a similar fashion, many other model studies also focus on sub-problems of transitions. Indeed, the border between 'transitions modelling' and other fields of modelling becomes blurred when the focus of the model is narrowed down. In their systematic literature review of ABM and socio-technical energy transitions, Hansen, Liu and Morrison (2019) observe that "the thematic contribution of the selected literature to the study of energy transitions lies more in addressing varied sub-components of the energy system than in modelling whole transitions" (p. 46). This indicates that most modellers who are interested in (certain aspects of) transitions are following the strategy to choose a more narrow focus.

The advantage of this strategy obviously is that a model of manageable complexity can be designed while the level of abstraction of the representation of actors and institutions may remain low, facilitating a comparably straight-forward translation of topical knowledge and (appropriate) social science theories into model components. It should be noted, however, that such models are (typically) not designed from a perspective of radical system change. Therefore, their results require some interpretation concerning their contribution to transitions research. Furthermore, insights from transition research about the co-evolutionary nature of transitions let us conclude that a narrow topical focus implies a limited temporal scale for which the chosen sub-system may be assumed to be sufficiently stable to allow abstraction from its interactions with the wider societal system.

6.2 Focus on building blocks

Another strategy, that is similar to the previously discussed one, also reduces the scope of the modelled system. The difference, however, is that the delineation of the target system does not follow a 'topical logic', but a 'transition theory logic', i.e. the delineation is rooted in transitions theory. Holtz (2011) suggests that breaking down the 'big story' of a transition into sub-processes would be useful starting point for the definition of more specific modelling studies of a reduced scope. Existing transition frameworks used by empirical researchers could be used to define such 'building blocks'. For example, Holtz (2012) combines the multi-level perspective with the multi-phase model (Rotmans, Kemp and van Asselt 2001) to dissect a transition into developments that occur in particular phases and on/across particular levels – such as niche-creation in the pre-development phase, or niche-regime interactions in the acceleration phase. The Multi-Pattern Approach (de Haan and Rogers 2019) would also be a useful framework to define sub-processes of the overarching transition.

A model that follows this strategy is presented by Lopolito et al. (2013). With their agent-based model they focus on the process of niche creation, which is a core concept of transition thinking as reflected in the multi-level perspective and strategic niche management (Schot and Geels 2008). In their model they include three mechanisms that are viewed as underlying niche creation (converging expectations, network building and empowerment, knowledge development and diffusion).

The advantage of this strategy over the previous one is that it facilitates an easier incorporation of and exchange with empirical and conceptual transition research, and provides a straight-forward way to feed model results into conceptual and theoretical discussions in the wider transitions community. A challenge is that the pre-existing knowledge concerning essential elements and processes of the suggested building blocks generating transitions is limited in many cases. While there is quite some knowledge available on niche creation, there is, for example, much less known about niche-regime interactions. A main challenge thus is the selection of the essential actors, institutions and technologies for the modelling of building blocks. This challenge, however, at the same time is an opportunity for modelling to contribute to conceptual and theoretical advancements when the model purpose is rather understanding and theory building than policy advice.

6.3 Focus on key actors and institutions

A third approach to define an appropriate sub-system is selecting key actors and institutions, and developing a model that represents (only) those at high level of detail. The rationale for selecting the actors is focussing on actors who have command over large resources and whose decisions are thus key for the future development of the whole societal subsystem of interest. Institutions are selected according to their influence on these key actors.

EMLab-Generation is an example which simulates investments of electricity producers in power generation capacity given a complicated set of EU and national policies on CO_2, on renewables and on security of supply (Chappin et al. 2017). The model is rooted in economic theory of investments in energy markets, it models policies to a very high degree of detail and studies effects across borders with policy differences. The model captures key processes in the energy transition: investments in energy supply, penetrating renewables in a system in which a strong regime exists, protected by vast assets and large companies. EMLab-generation is the result of a collaborative modelling effort spanning four PhD theses, with foci on different policies (climate policies, capacity mechanisms) and against different assumptions with respect to investment behaviour. The work led to insight in how the core climate policy instrument in the EU, the emissions trading scheme, could be improved and contributed to policy changes. It proved very useful in complementing prominent modelling work in the area of energy transition scenario development, which have serious blind spots in the conditions under which such scenarios would or would not materialize. I.e., it complements scenario development work (*what* would be a lowest cost pathway and end state for the energy transition) with what-if type of analysis (*how* transition paths for the energy transition may unfold).

The advantage of this strategy of focussing on key actors and institutions – similar to the strategy 'focus on sub-problem' – is that a model of manageable complexity can be designed while the representation of actors and institutions may be very detailed and close to empirical information. The main difference to the 'focus on sub-problem' strategy and an additional advantage is that a long time-horizon and a large spatial scale is covered. The EmLab-generation model, for example, simulates the path dependence in scenarios up to 2050 and covers multiple national electricity systems, simulating the effects of differences in policies.

A challenge for this strategy is that the explanatory power of a model that focuses on a few actors only hinges on the persisting power of those actors to shape the system's developments. In the typology of transition pathways developed by Geels and Schot (2007) that synthesizes insights from analysis of historical transitions into a typology of four different pathways, powerful incumbent actors survive in the 'transformation' and the 'reconfiguration' pathways. That means that assuming persisting influence of a few key actors may be a valid in some cases, but not in others – while it is typically not known ex-ante which pathway a specific transition will follow.
Another challenge for this strategy is defining (dynamic and co-evolutionary) influences on the selected key actors – in particular institutional and societal change – as exogenous input to the model. In the example of the EmLab-generation model this includes inter alia the phase out of particular electricity generation technologies such as coal due to societal pressure, and the penetration of the system with small-scale decentralized renewables power production plants. This challenge can be addressed if the variables that represent those influences are changed between multiple runs (see Moallemi et al., this volume).

6.4 Defining large-scale social entities

Acknowledging the large amount and diversity of actors and institutions involved in transitions, this strategy nevertheless aims at representing transitions in their full scope. To achieve this, the main approach is abstracting from single actors and rules. Hence, such a model represents emergent social entities on higher levels of aggregation, and uses stylized representations of their interactions.

A prime example of this type of model is the MATISSE model, which is presented and discussed at length by Köhler (this volume). Building on an extended multi-level perspective, this model focuses on a regime and niches, and develops a range of attributes and processes to represent these social entities and their interactions. The niches and regimes aggregate and abstract from a number of different actors including producers (along the respective value chains), intermediaries, and governmental actors who support particular solutions. Niches and regimes also subsume the institutions that provide the 'glue' between the different actors in a regime/niche.

The benefits of this strategy arise from its ability to combine a 'full scope' perspective with the inclusion of social aspects[7] and to unleash the power of formalization and computational experiments to study transitions on this level of aggregation and from this angle.

A main challenge for this strategy resides in the foundation of the specific design of model components and processes. To our knowledge, theories that provide a mechanistic understanding of the behaviours and interactions of large scale social entities such as regimes and niches are scarce and not formalized. The resulting need to 'make up' model components and processes opens room for critique. For example, Holtz (2011) observes that "(d)ue to a lack of useful theories, most of the mechanisms generating the dynamics of the MATISSE model were conceived based on the intuition of the transition researchers involved." (p. 175). Nevertheless, we argue that due to its particular benefits, this model design strategy has its merits, if its limitations are well balanced with the purpose of the modelling exercise.

7. Conclusions

Our discussion has shown that ABM is well suited for representing processes that emerge from the behaviours and interactions of bounded-rational actors and (changing) institutions that guide and constrain those actors' behaviours. This ability of ABM provides a unique opportunity to relax rigid assumptions with regards to homogeneity and rationality of actors that are often implicit in widely used economic approaches to the modelling of innovation for sustainability. ABM allows development of a bottom-up representation of (some selected sub-process of) a transition, and in particular representing social aspects and the co-evolution of technical and social elements of a system.

The multitude of actors and institutions involved in transitions requires that the modeller makes a selection of the involved actors and institutions for representation in the model, or boldly abstracts from single actors and institutions. Empirical and conceptual work in transition research does not provide a clear and widely shared conceptualization of actors and

[7] Capturing fundamental social aspects of the dynamics of transition processes is a main limitation of the process understanding implicit in other modelling approaches that are able to capture a 'full scope' perspective (see Köhler & Holtz, this volume).

institutions, which leaves considerable freedom to the modeller, but also creates the necessity to explain and substantiate the choices made. Some transition scholars have made some in-roads towards the conceptualization of actors and institutions that may serve the modeller as guidelines when designing a model.

We have identified four strategies for selection and abstraction of actors and institutions that follow different rationales and have different benefits and challenges. They are: 1) focus on sub-problem; 2) focus on building-blocks derived from transition concepts; 3) focus on key actors and institutions; and 4) defining large-scale social entities. The selection of a strategy for a particular modelling task needs to be in line with the purpose that this particular model shall serve. When developing an agent-based model, the interdependencies between a model's purpose, it's design and resulting complexity, data availability, and validity are always very delicate, and providing general insights and guidance is difficult. It is therefore beyond the scope of this chapter to provide a more extensive guideline which strategy is best used for what purpose and context.

The existing literature of ABM of transitions shows a strong bias towards the strategy of focussing on a sub-problem of the overall transition. This includes many models that have not been developed explicitly as 'transition models', but can be classified as belonging to this category within the frame of reference we have chosen in this chapter. While there are indeed plenty of opportunities to define and model highly relevant sub-problems, we also see high potential in following the other strategies we have identified. In particular we see a high potential for the strategies 'focus on building-blocks' and 'defining large-scale social entities' to establish closer collaboration between transition modellers and researchers working with qualitative methods, and to advance the conceptual and theoretical base of transition research. The strategy of 'focussing on key actors and institutions' is promising for policy advice about (possible) long-term developments, in particular in combination with exploratory modelling. We therefore encourage ABM modellers to develop modelling exercises following those other strategies.

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