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How does the Multi-Level Perspective help to enhance a System Dynamics analysis of a specific transition challenge?

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Abstract

This paper addresses the challenge of identifying adequate theoretical starting points for problem oriented simulation studies of socio-technical transitions towards near fossil free energy services e.g. for housing and transportation. The identification of adequate starting points for simulation studies is becoming increasingly important for the generalization of simulation results as well as for theory refinement. We found that the Multi-Level Perspective (MLP) offers a helpful language for a modelling experiment based in a feedback perspective. This allows the conceptualization of a socio-technical transition challenge departing from an inter-subjective and hence scientific starting point. In addition feedback modelling appears to be a promising mathematical analysis approach that helps to substantiate the MLP. We have seen that the insights of the simulation experiment corroborate basic assumptions of the MLP concerning multi-level alignment processes but also discriminate the decisive determinants and governance mechanisms that explain radical innovation and subsequently the creation of path dependency.

1. Introduction

This paper addresses the challenge of identifying adequate theoretical starting points for problem oriented simulation studies of socio-technical transitions towards near fossil free energy services e.g. for housing and transportation. Problem oriented analysis refers to practical challenges such as accelerating the diffusion dynamics of energy efficient housing, substitution dynamics of clean drive-drain technologies, or niche-market development of electric transportation concepts in an early innovation stage, where the valley of death still needs to be overcome. The identification of adequate starting points for simulation studies is becoming increasingly important for the generalization of simulation results as well as for theory refinement (Ulli-Beer and Wokaun 2011:900). The multi-level perspective (MLP) on socio-technical transitions (Geels 2002; Geels, Hekkert et al. 2008) offers a helpful heuristic that points to typical alignment processes at the micro, meso and macro level of a socio-technical transition. It also defines what basic sub-systems and elements should be considered of a socio-technical system including actors and organisations with their decision rules (institutions) of both the production side and application domain. In the last decade research concerning MLP has made strong progress in consistently conceptualizing a framework as narrative explanations grounded in case studies and interdisciplinary theories (e.g. Geels 2004; Geels 2010). The authors have developed analytical concepts that have been used to empirically analyze historical and ongoing transitions and to develop a typology of transition pathways (e.g. Geels 2002; Belz 2004; Geels 2005; Geels 2006; Geels 2006; Vleuten and Raven 2006; Geels and Schot 2007; Raven 2007). Most recent studies demonstrate how the MLP can be enriched by complementary theories in order to analysis specific adjustment dynamics of transitions (Markard and Truffer 2008; Nill and Kemp 2009; Elzen, Geels et al. 2011).

In parallel to these narrative approaches on socio-technical systems, formal models have been used for analyzing longitudinal patterns of evolution (Safarzynska and Van den Bergh 2010). However, the application of bi-directional coupled models is still in its infancy (Ruth, Kalnay et al. 2011). A promising field for further advancement along this direction is the research field of System Dynamics, which has already proven some very inspiring applications (Meadows, Meadows et al. 1972; Meadows, Randers et al. 2004; Timmermans, Haan et al. 2008; Turner 2008; Yücel 2008). System Dynamics embraces a feedback perspective (FBP) based on the epistemological assumption that system behaviour arises endogenously from feedback loop structures (i.e. causal circularities). The field has been inspired by control theory and nonlinear dynamics (Forrester 1968; Richardson 1991). The SD research stream contributes to both the enhancement of a meta-theory of complex dynamical (social) systems and the development of context specific middle range theories in application domains. In order to support structural understanding it has developed a codified visualization syntax. An important research challenge of this approach is “the blank piece of paper” challenge as illustrated by Coyle’s statement:
“The system dynamics practitioner is always faced with a blank piece of paper at the outset of a study, unlike the linear programmer who knows in advance that the model must consist of a set of linear constraints of certain types and a linear objective function” (Coyle 1996). This challenge refers to the choice of the adequate starting point for the problem at hand. This is critical if simulation exercises are used for the scientific task of theory building in an application context.

System dynamics simulation frameworks have increasingly been used for conducting comparative policy and scenario analysis addressing the impact of radical innovation pathways (Janssen, Lienin et al. 2006; Weil 2007; Stepp, Winebrake et al. 2009; Ulli-Beer, Bosshardt et al. 2009; Harich 2010; Park, Kim et al. 2011; Yücel and Daalen 2011). However, the starting point(s) for such modelling exercises often have been determined either by the managerial problem situation or by interdisciplinary composed concepts but rarely by generalized transition frameworks currently under discussion. Yücel (2008) has nicely discussed the power of System Dynamics simulation for understanding the complexity of transition dynamics. However the value added of applying an organizing reference theory for such a simulation exercise has not yet been elaborated. In particular the contribution of the MLP for simulation exercises and vice versa has rarely been discussed in the emerging field of environmental innovation and societal transitions.

This article seeks to address this gap and explores how the MLP helps to enhance the scientific contribution of a simulation exercise that aims at analyzing a specific transition challenge. Its contribution is threefold.

-First it shows how the MLP helps to position a problem oriented modelling exercise into a scientific reference framework.
-Second, it shows how the MLP helps to advance the findings of a simulation exercise.
-Third, it discusses the merit of simulation based transition analysis for enhancing the understanding of transition processes as well as for long term policy analysis. Most importantly, it discusses how a single simulation experiment can be pushed further in order to enhance theorizing on dynamics of transition processes.

In order to address these aims we have chosen a two step approach. First, we compare key characteristics of the MLP and the FBP in order to understand the differences and commonalities of both approaches. Secondly we report on a typical simulation experiment that explains the diffusion dynamics of energy efficient buildings in Switzerland. This illustration provides the basis for elaborating the value added of the MLP as the reference frame for the simulation experiment. Lessons from the modelling exercises are discussed by addressing the following questions:
- How does the MLP help to conceptualize a simulation experiment of a specific transition challenge?
- How does the MLP help to organize and reclassify the insights about system structure and dynamics of socio-technical transitions?
- What is the value added of a simulation based analysis of socio-technical transitions?

Chapter 2 begins with the systematic comparison of both perspectives. The illustrative simulation experiment and its main findings are described in chapter 3. The value added of an integrated approach that combines scientific theorizing, data analysis with simulation is carved out in chapter 4. The last chapter discusses the main observations and concludes with recommendations for further research into integrative simulation approaches on sustainability transitions.

2. Research grounds of the Feedback and the Multi-Level Perspectives

In this chapter the research grounds of the feedback perspective on dynamical complexity applying numerical simulation and the multi-level perspectives will be discussed. The differences and complementarities of both research perspectives will be analyzed in order to assess if and what additional insights from an integration of both perspectives and approaches can be expected.
Specifically for the research task of theory-building a clear understanding of the research focus and content concerning the level and unit of analysis, as well as the theoretical grounds and propositions are decisive in order to assess how far both perspectives are suitable for integration. In the following, each perspective will be described along these organizing elements. For this overview basic publications from experienced authors in each field have been consulted (i.e. Forrester 1968; Richardson 1991; Sterman 2000; Lane 2001a; Ulli-Beer 2006; Ulli-Beer, Bruppacher et al. 2006; Geels and Schot 2007; Geels, Hekkert and Jacobsson 2008; Schot and Geels 2008; Schwaninger and Grösser 2008; Timmermans, Haan and Squazzoni 2008; Geels 2010; Van den Bergh, Truffer et al. 2011).

2.1 What are the specifics of the Feedback Perspective on socio-technical transition modelling?

The field of System Dynamics explains dynamical complexity by causal circularities that reflect a closed loop understanding of the world. Therefore I refer to this understanding as the feedback perspective (Forrester 1968). Through intertwined loops of "perceived action pressure $_{(t)}$ - response - state adjustment - perceived action pressure$_{(t+1)}$ -…" sequences, each person is continually reacting to the echo of that person's past actions as well as to the past actions of others and further system state adjustments (e.g. capacity levels, infrastructure states, standards). Based on this FBP, the System Dynamics field has developed a meta-theory and methodology of high rigor for the analysis and simulation of dynamical complex (social) systems in the last fifty years. Its application in the context of socio-technical transformation towards "greener" economies with less energy consumption and lower CO_2-emissions is regarded as an applied scholarship of numerical modelling. The modelling principles are based on differential equation models in the form of

$$r = \frac{dx}{dt} = f(x,u)$$

where *r* is a vector of rates associated with *x*, a vector of states. The rates are some nonlinear functions *f()* of the state-vector *x* and *u*, a vector of exogenous inputs that includes the parameterization of table functions.

Level of analysis: According this scholarship the research focus of a scientific simulation experiment lies on middle range theory building on dynamic phenomena of a class of systems. The levels of analysis are endogenous feedback processes and their behavioral implications within a socio-technical system.

Unit of analysis: The goal of research is to explain the dynamical phenomena in terms of underlying determinants and coupled feedback loops that drive co-evolution of important (state) variables of a socio-technical system. The boundary is delineated empirically with regard to both the phenomena of interests (i.e. direction and rate of innovation and diffusion) and hypothesised endogenous circular causalities of its diachronic process (i.e. system change over time). The analysis focuses on rules of interactions between elements and (sub)-system structures with its specific patterns of behaviour. Elements are agents and institutions, physical and technological artefacts as well as system resources, with their specific decision or interactions rules, respectively.
The scientific simulation experiment aims at gaining multi-dimensional insights and understanding not only with respect to insights about structure and dynamics of the rate and direction of innovation but also with respect to specific behaviour patterns such as path dependence, overshoot behaviour, or policy compliance and resistance.

Theory frame: The theory of nonlinear dynamics is used as the meta-reference frame. Patterns of change are explained by nonlinear shifts between the dominance of specific loops. In addition interdisciplinary concepts from sociology, psychology, (evolutionary) economics, and management guide the scientific conceptualization of a (dynamic) hypothesis concerning the transition pathway.

Theoretical propositions: Two theoretical research questions are guiding the modelling and simulation task: “What is the basic feedback structure responsible for the observed system behaviour?” and “What feedback structures exist but have not yet played a significant role?”

Key propositions are formulated on the basis of specific characteristics of causal circularities. Those who are most relevant for transition modelling refer to growth and limits to growth; to equilibrium and stability; to path dependency and system change. Positive loops are responsible for growth or decay processes. Negative loops become dominant if various limits to growth are approached. Powerful negative feedback processes are keeping the state of the system nearly constant even in the face of environmental disturbances. Stability arises through highly effective goal-seeking behaviour. Path dependency is a pattern of behaviour in which small, random events early in the history of a system determine the ultimate end state. It is the result of dominant positive feedback processes and arises in systems with locally unstable equilibria.

As a system evolves, latent feedbacks may become dominant, and may dramatically change the behaviour pattern. In nonlinear systems, the feedback loops and parameters governing the dynamics vary, depending on the state of the system. Such adaption processes may result in shifts in loop dominance explaining simulated (and observed) transition paths.

This overview about the FBP on socio-technical transition modelling evidences two promising characteristics of the feedback perspective: First, based on circular causalities it offers a mechanism based explanation that allows the formulation and testing of ‘what-if’ questions. Specifically it allows testing the relevance of postulated elements and sub-structures, their properties and rules of interactions that is to test their ability to make a relevant difference within the transition pathway.

Secondly, the 50 years old scholarship also provides a methodology about best approaches towards modelling of dynamical complexity. This is an important basis for a rigorous modelling and simulation approach on socio-technical transitions.

However, the limit of this numerical simulation approach is also connected with its strong methodological reflection. It misses an application oriented scholarship, specifically in the domain of socio-technical transition. Therefore, there are strong deficiencies in the development of a common language community that would allow for discussing and enhancing the relevance of simulation based insights.

2.2 What are the main conceptual contributions of the multi-level perspective?

The MLP is promising as a general frame of reference for forming a language community within the field of sustainability transitions. It provides a heuristic for inquiry that helps formulating hypothesis for testing. In this section I will evidence how the MLP makes an important contribution not only for the emerging field of sustainability transitions but also for guiding simulation based theory refinement, specifically for simulation experiments informed by feedback thinking.

Level of analysis: The MLP is considered a process theory that postulates that social reality is not a steady state but a sequence of individual and collective actions unfolding over time in a context. It serves as a heuristic for conceptualizing a middle range theory about transitions within a socio-technical system that is delineated by its fulfilment of a societal function (e.g. transport, communication, housing …).

Unit of analysis: The goal of research is to explain the dynamical phenomenon of radical innovation and diffusion as co-evolutionary processes between and within the five different regimes i.e. science, technology, economy, politics, and culture. The alignment processes may be triggered either by niche dynamics or landscape changes. Elements of a socio-technical system are actors, rules/institutions, system resources and artifacts, as well as multi-level alignment processes. The MLP aims at gaining multi-dimensional insights and understanding, for example concerning type and role of agency, the structure and dynamics of the rate and direction of innovation and diffusion, and types of transformation pathways. This perspective should help to give more attention to the governance criteria of “social-political feasibility” complementing the “efficiency criteria” of an economic perspective.

> “It takes the inter-organisational community of field as the unit of analysis, and focuses on the social infrastructure necessary to develop, commercialise and use innovations” (Geels 2004).

Theory frame: The MLP is considered as a flexible framework that has crossovers to meta-theories such as evolution theory and interpretivism. It frames the topic of transitions as multi-level alignment processes (landscape, regime, niche) and co-evolution (science, technology, economy, politic and culture) explaining the structuration of activities in local practices over time.

Theoretical propositions: The MLP gives particular answers to the two questions: What mechanisms create stability and incremental innovation? How does radical innovation emerge? First, stability and incremental innovation are explained by path dependency arising from three system elements: 1. Rules and regimes provide stability by guiding perception and actions. 2. Actors and organizations are embedded in interdependent networks and mutual dependencies which contribute to stability. 3. Socio-technical system, in particular the artefacts and material networks, have a certain ‘hardness’ which makes them difficult to change. Second, instability and radical innovation are explained by niche dynamics or as “tension” induced adjustment processes. Niches are seen as one seed of change: Since rules in niches are less clear and the structuration of activities is less pronounced, there is more space to go in different directions and try out variety. The tension and misalignment propositions refer to tension and mis-matches of activities between multiple social groups and certain rules within the socio-technical regimes. These tensions create the need and space for interpretative flexibility for actors. The origins of tensions are attributed to five domains: changes on the landscape level, internal technical problems, and negative externalities, as well as changing user preferences, strategic and competitive games.

In sum, the overview shows that over the past decade the research stream on the MLP has established a common understanding and a distinct and well-defined language about a socio-technical system that allows for discussing inter-subjective assumptions that goes beyond meta-theoretical considerations about dynamical complexity. Such a common language community is important for a scientific field. Becker (2003) states that an unique language community is the constituting difference between pre-scientific and scientific cognition.

In addition, the multilevel perspective offers two conceptual advantages: First with its research focus on how the fulfilment of a societal function (e.g. transport, living) is improved - either by incremental or radical innovation, it theoretically guides the boundary delineation for its practical application. Second, it offers a framework that helps to structure the practical transition situation in a systematic way, but without applying ex ante assumptions that may lead to an oversimplification or a narrow misconception of the problem situation. It does so by highlighting some foundational mechanism, by offering analytical concepts (e.g. actor and rule categories) as well as a typology of transition pathways. However, it still leaves room to operationalize the sensitizing concepts and to define the case specific causal circularities. So far however, there has been little discussion about methodologies that support this kind of analytical rigor and that help to quantitatively and theoretically discriminate the specific transformation mechanisms in a synergetic manner. Further research in this direction will help to enhance theorizing with rigorous mathematical models and to substantiate the MLP perspective.

2.3 What is the allure of the MLP for simulation experiments on socio-technical transition task

In the former section an overview about the specifics of the multi-level and FBP on sustainability transition have been given. In this section the differences and complementarities of both research perspectives will be summarized. The discussion should give a clear answer to what extent feedback modelling with its key concepts can be integrated within the MLP and what value added can be expected from an integration of both perspectives.

The comparison in Table 1 between the research content of the MLP and FBP mirrors the differences in the applied language as a result of the different levels of abstraction of both perspectives. While the MLP terms are grounded in the application context of socio-technical transitions, the FBP terms reflect the scientific language of nonlinear dynamics and the methodological modelling jargon.

A systematic comparison of the research focus along the presented levels however, shows that there are strong similarities regarding the level and unit of analysis. Both perspectives are dealing with a process theory, where sub-systems and their elements are responsible for a dynamical phenomenon. Rules of interactions are decisive. But there are differences in the theory frame and the main analytical concepts. While in the MLP the elements and the subsystem have been named, the FBP offers no material guidance. Also, the main theoretical concepts are described in a very different language. We could say the MLP applies a descriptive term frame, with a static understanding, to some extend, while the FBP applies a methodologically oriented process description. But the explanations of both perspectives are not conflicting but rather complementing. The FBP offers technical concepts for the systemic process analysis, whereas the MLP offers descriptive analysis concepts that help structure the transition situation in a scientific, field specific and practicable term frame.

A final observation can be helpful for assessing the compatibility. Within the MLP research literature the authors are often using terms such as accumulations, circular causalities, feedback or nonlinearities. This observation gives evidence of similar conceptions at a more abstract and technical analysis level. Although the methodology has not yet been systematic elaborated in the MLP field, there seems to be some interesting synergies between both perspectives.

In sum, we have seen that the differences in the research content are not conflicting but rather complementing each other. The MLP offers a term and concept frame for the scientific description and structuration of the transition context. Contrarily the FBP offers a distinct analytical term and concept frame that is helpful for rigorous analysis of causal circularities within a transition context. We can conclude that the MLP framework offers a helpful language for a modelling experiment based in a feedback perspective. This allows scientific conceptualization of a socio-technical transition challenge departing from an inter-subjective and hence scientific starting point. In addition feedback modelling appears to be a promising mathematical analysis approach that helps to substantiate the MLP. There exists a natural affinity between both perspectives suggesting that they can be integrated.

	Research focus	Research content MLP	Research content FBP
Level of Analysis	Middle range theory building	Level of analysis are transitions within a socio-technical system that is delineated by its fulfillment of a societal function (e.g. transport, communication, housing …)	Level of analysis are endogenous feedback processes and their behavioral implications within a socio-technical system that is delineated by a dynamical phenomena
Unit of Analysis	Aims at multi-dimensional insights	Explain a dynamical phenomenon. Understand the co-evolution of the five different regimes: science, technology, economy, politics, culture i.e. co-evolution of new technologies, changes in markets and user practices, political and cultural meaning	Explain a dynamical phenomenon. Understand the underlying determinants and coupled feedback loops that drives co-evolution of important (state) variables of socio-technological system
	Interactions between structures and resulting behavior	Elements are actors, rules/institutions, system resources and artifacts, multi-level alignment processes	Identifying important stocks and variable system elements as well as their specified rules of interactions with its behavior patterns
Theory Frame	Main heuristic	The multi-level perspective is a flexible framework with crossovers to meta-theories such as evolution theory and interpretivism.	Theory of nonlinear dynamics: Nonlinear shifts in loop dominance explain system change
	Fragmented disciplinary concepts	Theories from sociology, psychology, (evolutionary) economics, management science etc. guide the scientific argumentation	Theories from sociology, psychology, (evolutionary) economics, management science etc. guide the scientific conceptualization
Main concepts	Limits to growth	Implicit explanations are given by the tension concept	Positive loops are responsible for growth or decay processes. Negative loops become dominant if various limits to growth are approached
	Equilibrium / Stability	RQ: What mechanisms create stability and incremental innovation? Stability arises through stable decision heuristics	RQ: What is the basic feedback structure responsible for the observed system behavior? Powerful negative feedbacks create stable equilibrium.
	Path dependence	PD results from: 1. Stable rules 2. Mutual depending actor networks. 3. Physical artifacts and material networks	PD is the result of dominant positive feedback processes and arises in systems with locally unstable equilibria.
	Instability	RQ: How does radical innovation emerge?	RQ: What structure exists but has not yet played a significant role?
		1. Niches as the seed of change. 2. Tension and misalignment in regimes	Shifts in loop dominance alter the behavior mode (explain transitions): As system evolves, latent feedbacks may become dominant.
		A Changes on the landscape level, B Internal technical problems, C Negative externalities, D Changing user preferences, E Strategic and competitive games	In nonlinear systems the feedback loops and parameters governing the dynamics vary depending on the state of the system.

RQ: Research Question; PD: Path Dependence

Table 1

3. An illustrative simulation experiment on a socio-technical transition task

In this section we present an illustrative simulation experiment and its main findings concerning a socio-technical transition as a basis for the methodological discussion later on. The project was part of the National Research Program 54 “Sustainable Development of the Built Environment” of the Swiss National Science Foundation. The research design of the project called “Diffusion dynamics of energy efficient buildings DeeB[1]” has been strongly informed by the scholarship of System Dynamics modeling. The main research question of the simulation experiment was: “Which factors and processes have played a role in the diffusion of energy efficient housing designs in the Swiss building sector?”

3.1 Empirical background

In Switzerland, environmental and energy politics has been anchored in the Swiss Constitution (i.e. Article 73 sustainable development; Article 74 protection of the environment and Article 89 for energy politics) (Swiss_Federal_Authorities 1999 (2011)). Also, Switzerland has signed the Kyoto Protocol in 1997, and consequently approved the CO_2-Law which prescribes that the CO_2 emissions need to be reduced by 10 percent below the reference value of 1990 until the year 2010. Although this federal legislation has been complemented with the vision of the 2000-watt society[2] in 1998 and several national and cantonal policy programs, the achievement of political targets regarding energy efficiency and reduction of green house gas proves to be very challenging. This indicates the need for further “governance” efforts, specifically in the domain of transportation and buildings. In contrast to this general observation, energy efficiency in new buildings has shown a very positive development in the last five decades (c.p. Jakob 2008). Therefore a better understanding of this success story and its governance mechanisms would help to transfer it to further domains in need of action.

An empirical study showed that gathering of exact longitudinal data on energy consumption from new built houses is a challenging task (Brühlmann and Tochtermann 2000; Dettli, Gsponser et al. 2003). Figure 1 summarizes the available information and illustrates the continuous decrease of energy demand of new built housings from 1970 till 2010 in Switzerland. While in 1970 a newly built home consumed around 800 MJ/m^2*year for heating and warm water, energy consumption has been decreased by a factor four resulting in an average of 200 MJ/m^2*year in 2010. However, these values may differ strongly, depending on regional location, type of housing and implemented energy standard. In the same time horizon the price of oil showed a different development. We can observe a decade with high oil prices from 1974 till 1984 due to the oil crisis, and two decades with relatively low energy prices from 1985 till 2005. While the oil crisis may explain the initial improvement in energy efficiency, the strong decline in energy consumption in the following two decades cannot be explained by the oil price

[1] Project Nr 405440-107211 of the National Research Program 54 of the SNSF
[2] “The vision of the 2000-watt society calls for a continuous reduction in energy needs to 2000 watts pro person” http://www.novatlantis.ch [accessed 8 August 2011].

trend. Instead other governance mechanisms such as informal and formal norm setting processes (i.e. building codes) gain importance (Groesser and Ulli-Beer 2008; Jakob 2008). These observations provided the empirical starting point for the simulation based case analysis.

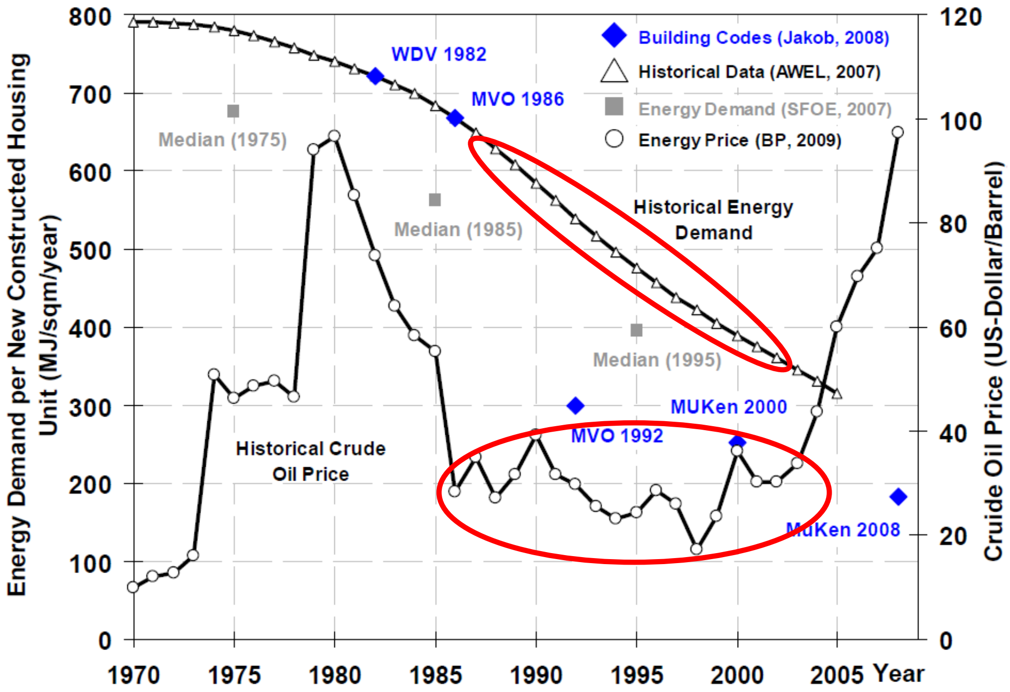

Figure 1: Comparison of energy demand of new buildings in Switzerland and the crude oil price development (adapted from (Groesser 2011 In press)).

3.2 The modelling exercise

The research approach

In order to analyze the historical socio-technical transition towards energy efficient housing a transdisciplinary and interdisciplinary research approach has been chosen (Ulli-Beer, Bruppacher, Grösser, Geisshüsler, Müller, Mojtahedzadeh, Schwaninger, Ackermann, Andersen, Richardson, Stulz and Kaufmann-Hayoz 2006). Psychological, managerial, and economic theories as well as results of empirical investigations about antecedents of behaviour choices have been analyzed by a structural equation model (Lauper 2009). These results have been synthesized into a simulation model for a middle-sized Swiss city (i.e. interdisciplinary perspectives). Therefore the relevant actors (i.e., public and private decision makers in the value creation chain of buildings) have been involved in the model building process (i.e. transdisciplinary perspective). In order to identify the relevant actors an iterative method of actor identification has been developed and successfully applied (Müller, Grösser et al. 2011 (in press)). The identified actors have been invited to participate in four workshops(c.p. Figure 2) in order to discuss the main conceptual assumptions and behaviour implications of the simulation model

(Groesser, Ulli-Beer et al. 2009). The applied techniques for participatory modelling have been informed by the literature about group model building (e.g. Andersen, Richardson et al. 1997; Howick, Ackermann et al. 2004).
The scientific aim of the modelling project was to shed light on dynamic interactions between behavioral factors (e.g., planning, decision making and routines of the relevant actors in the building sector) and contextual factors (e.g., technological innovations, public initiatives, and market conditions), thus explaining the diffusion of energy efficient buildings in a community.

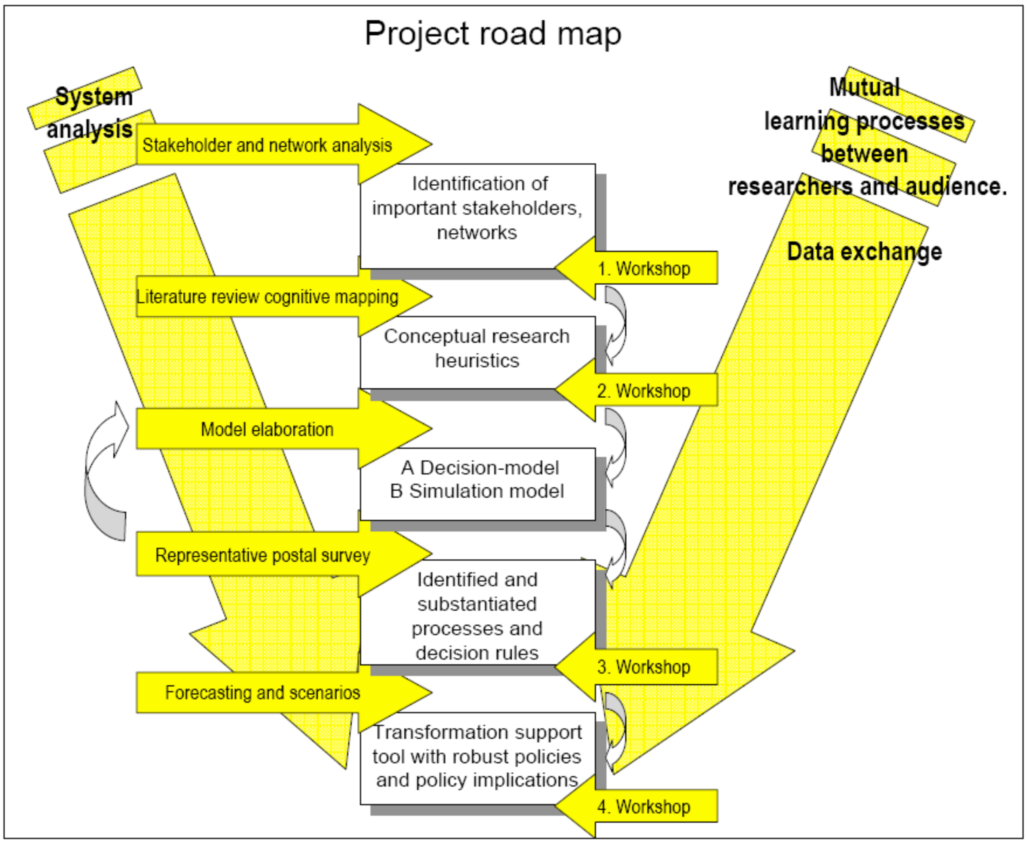

Figure 2: The project road map of the simulation experiment (Kaufmann-Hayoz, Bruppacher et al. 2005)

Main results

The actor identification process and boundary delineation task resulted in a first conceptual framing that emphasizes the feedback processes between actors' action (strategies) and their perception (expectation) of societal structures (Figure 3). In addition important actors influencing the actors of the value creation chain have been identified. At this point the importance of innovative actors groups promoting housing designs with low energy consumption standards have become salient; they actually had triggered the new ee improvement trajectory. In addition the Swiss association of engineers and architects (SIA) played a leading role in the process of developing and enforcing formal building codes) in support of the ee trajectory (e.g. in 1975 the SIA 380). Before the energy crisis, the SIA has developed mainly building codes addressing safety and quality requirements. But governmental agencies at the cantonal level (informed by the SIA) were responsible to prescribe and enforce mandatory energy-efficiency requirements of buildings – here some cantons played a leading role. National authorities, however, have elaborated together with the cantonal authorities prototype ordinances (Musterverordnungen from 1986, 1992, 2000, and 2008) that have to be implemented at the cantonal level (Jakob 2008).

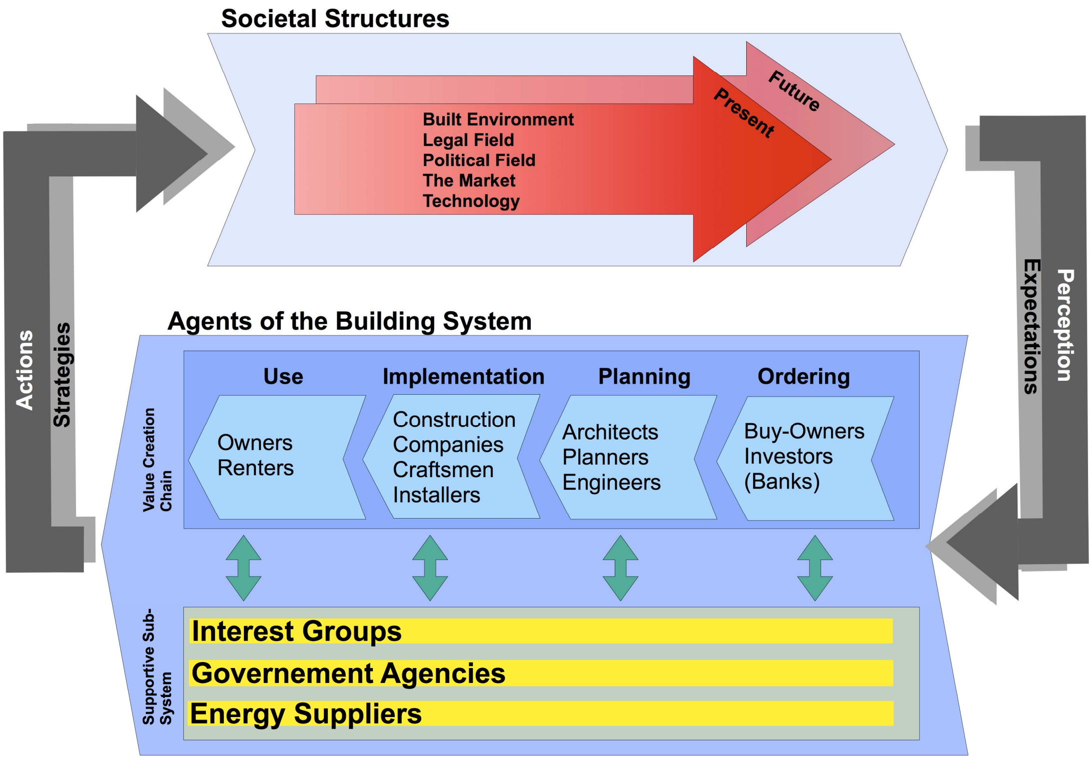

Figure 3: Basic circular causalities between actors' actions / strategies and societal structures that influence actors' perceptions / expectations (Müller, Grösser and Ulli-Beer 2011 (in press))

In the course of further investigations into literature and empirical data, a System Dynamics model has been conceptualized that formalized the rule of interactions between important actors and socio-technical context variables. This resulted in a quantitative simulation model that was able to replicate the historical development of different types of energy coefficients. Further-on, model analysis and mapping resulted in a so called causal loop diagram that visualizes the main model variables and feedback processes underlying the observed behaviour patterns. This model analysis process help to answer the research question: "Which factors and processes have played a role in the diffusion of energy efficient housing designs in the Swiss building sector?"

In the following these insights will be presented based on Figure 4. I will start with important external variables that trigger further mechanisms. The trigger variables are the price of fossil resources, the innovativeness of demand and supply agents as well as action pressure from energy supply and climate change threads. There are also two policy variables that represent the influence of governmental actions (‘official support for energy efficiency’ and ‘political desired energy demand target’). The effect of these exogenous inputs on the energy efficiency of housing units is explained by the six governance mechanisms illustrated by feedback loops. They can be either reinforcing R, producing exponential change, or balancing B enacting goal seeking behaviour towards an (implicit) system target: The mechanism <B1 Technology push> represent innovators, that are responding to a perceived gap between a (pressure indicated / political) ‘desired average annual energy demand’-target and ‘the actual average annual energy demand per housing unit’. The energy demand per housing unit has been reduced due to ‘research and development activities’ and improvement in the ‘level of technology’. Since ‘Energy demand of the innovative standard’ is based on accumulated technology developments, it is modelled as a state variable – marked with a rectangle. This balancing mechanism triggers four reinforcing mechanisms that produce exponential change in the respective state variables. The mechanism <R1 Learning by doing> governs the ‘experience base with ee housing technology’ of supply agents, <R2 Acceptance dynamics> control the ‘installed based of ee housing units’, the mechanism <R3 Market pull> regulates the ‘relative capacity to construct ee housing units’ of supply agents, and <R4 Economies of scale> support the reduction of ‘energy demand of the building code’. These governance mechanisms are regulated by interaction rules; for example the utility calculation derived from the different attributes of ee housing and changing preferences labelled as “familiarity with and reliability of ee housing units’.

The adjustment processes are slowed down due to response delays. Delays are marked with double bars across the causal relation arrows. The adjustment processes are twofold balanced. First, they are balanced by the goal seeking loop <B1 Technology push> that tries to close the gap. Second, the mechanism <B2 Limits to reduction> stabilizes the adjustment process as soon as the agents of the standard setting association perceive higher ‘marginal benefits of alternative investment trajectories’ compared with the ‘relative marginal benefits of the ee trajectory’, that limits their ‘willingness to reduce energy demand of the building code’. Currently, this balancing mechanism becomes dominant in Switzerland. It is reflected in the discussion about unreasonable insulation practices that tend to overplay the thermos bottle principle.

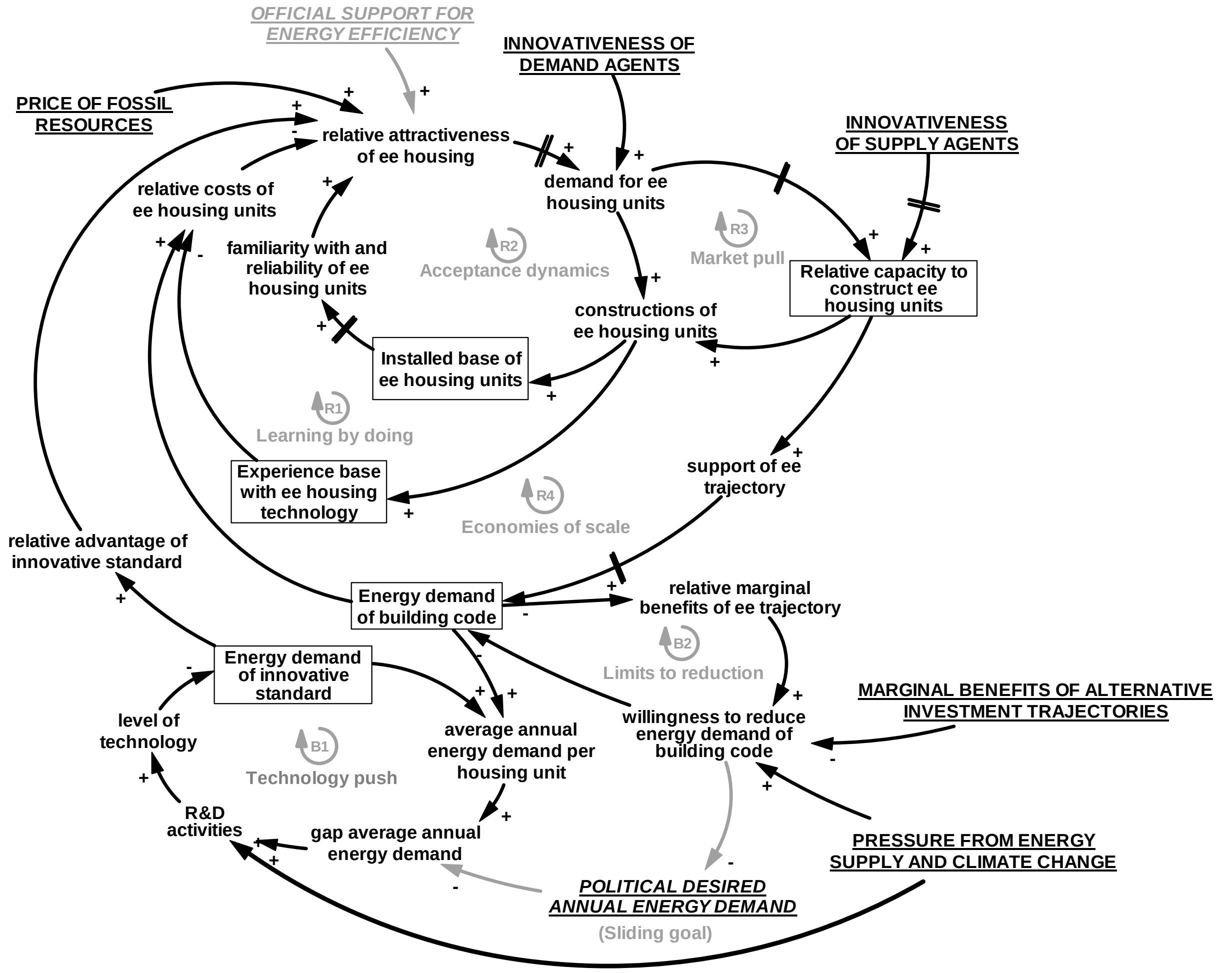

Figure 4: Basic factors and processes that have played a role in the diffusion of energy efficient housing designs in the Swiss building sector?” (enhanced from Groesser and Ulli-Beer 2008)

Discussion of the results

The interdisciplinary and transdisciplinary research approach was adequate for answering the leading research questions: ”Which factors and processes have played a role in the diffusion of energy efficient housing designs in the Swiss building sector?”

Based on the simulation experiment, a fairly well empirically founded causal loop diagram could be deduced that has the power to causally explain the diffusion of energy efficient housing designs in Switzerland in a coherent way.

We specifically have seen that exogenous variables (price of fossil resources, the innovativeness of “entrepreneurs”, and long term policy pressures from energy and climate change) triggered radical innovation shaped by the co-evolution between behavioral factors of actor groups as well as contextual factors of the socio-technical environment. This means that on the one hand preferences for ee housing of the different actor groups have been built up and enforced over time and that product characteristics of ee housing designs have improved in such a way that the interaction rules (e.g. utility calculations) resulted in higher adopter potentials for ee housing designs. The same is true for the implementation of new and enforced standards as well as policy targets.

In other words, external factors have triggered the new improvement paradigm energy efficiency (ee) in housing designs and (i.e. radical innovation) as a new norm within different actor groups (standard setting authorities, supply and demand actors as well as policy makers). The new norm has not substituted the primary performance attributes of housing in general such as costs and quality but created a complementary improvement trajectory. Generic reinforcing mechanisms of incremental innovation and diffusions supported the ee improvement trajectory till it gained enough strength to create the new dominant ee housing design for the mass market. This means that co-evolutionary processes has generated a shift in the loop dominance of the mechanisms supporting energy efficient housing designs over the main generic mechanism supporting traditional housing designs – hence redirecting the existing pathway towards energy-efficiency.

In addition to this systemic explanation of the interplay between behavioral and contextual factors, the analysis has shed light on the role of two mechanisms that has not get a lot of attention in the scientific literature so far. These are the mechanism <R2 Acceptance dynamics> that represent changes in preferences, and mechanism <B2 Limits to reduction> that reflects the ending of an attribute specific improvement trajectory. Also, we have seen that the pace of the diffusion process depends on the co-evolution of subsystem specific state variables that influence the result of the interaction rules coordinating multiple feedback loops. Consequently, those policy packages are effective that are influencing the outcome of interaction rules in favour of ee housing designs, i.e. the utility calculation of the variable ‘relative attractiveness of ee housing designs’ and the calculation regarding the need of action of the variable ‘gap average annual energy demand’ influencing invention and innovation concerning ee improvements. This has been done by setting the sliding goal ‘politically desired annual energy demand”. The sliding goal behaviour resulted from changes in the state of system that legitimated the enforcement of ee standards over time. The target setting process and the balancing loop <Technology push> is critical for understanding both the directional stability and enforcement of the ee improvement trajectory. It actually has overridden profitability consideration of demand agents during the low energy price phase from 1985 to 2005.

In sum, we have seen that the simulation exercise has provided valuable insights for system understanding and policy design. However, the overall approach has also its limitations. Empiricism was methodically very challenging and compared to narrative and qualitative system analysis, it was very time- and cost- consuming. In addition, the communication of the overall approach and the findings to a scientific community is very challenging, since the approach contradicts disciplinary research practice in different ways. Firstly, the main insights are multi-dimensional based on the synthesis of knowledge rather than on analysis into a one-dimensional defined concept. Second, the approach combines concepts from different disciplines that do have no common scientific research community. Finally, the utility of the simulation model cannot be valued by traditional one-dimensional validity parameters, and therefore the quality of the overall research is more challenging to communicate. In addition simulation approaches still have an acceptance problem in the mass market of the social science community, because the experience base is still rather low.

4. Reflecting the simulation experiment from the MLP

In this chapter I us the multi level perspective to reflect the simulation experiment described above. The practical case is used to test and illustrate the theoretically derived statements in chapter 3 concerning what additional insights from an integration of both perspectives and approaches can be expected. To commemorate, the statements suggest that first, the MLP framework offers a term and concept frame for the scientific description and structuration of the transition context. Second, it allows the scientific conceptualization of a socio-technical transition challenge departing from an inter-subjective and hence scientific starting point. Third, the FBP offers distinctive analytical concepts for a quantitative process analysis based on causal circularities.
For the case specific discussion of the statements, we follow the research strategy framework specifically developed for integrative innovation system modelling (Ulli-Beer and Wokaun 2011). We show in a first step how and in which research phase the MLP helps to conceptualize and interpret the specific simulation experiment. We also show how the MLP helps to interpret the insights and how it enhances theorizing of socio-technical transitions. In a second step, we discuss the value added of the simulation experiment for the enhancement of the MLP.

4.1 MLP as reference frame

The motivation of the simulation experiment has been the general societal problem situation of growing energy demand and CO_2 emissions that is perceived in a subjective way by different actors (Müller, Grösser and Ulli-Beer 2011 (in press)). The building sector has been identified as an important energy consumer where ee measures promise to have a significant saving effect (Levine, Uerge-Vorsatz et al. 2007). The selection of the case “energy-efficiency in new housing units” was guided by empirical observation of the diffusion of energy efficient housing units that actually was interpreted as in need of being accelerated at a first glance. From a scientific perspective this situation was related to interdisciplinary concepts in need of integration by the systemic FBP(Kaufmann-Hayoz, Bruppacher and Ulli-Beer 2005). Further investigations into the messy problem situation, also taking into account practitioners ‘personal theories’ lead to a clear description of the energy consumption phenomena from a static perspective as well as a dynamic perspective. While the static perspective showed some improvement potentials (Bruppacher 2009), the dynamic perspective identified the case “energy consumption of new housing units” as a success story . The latter empirical specification has allowed pushing scientific thinking beyond the initially proposed interdisciplinary perspective. Concretely, it qualifies the dynamical phenomena as an interesting case for a MLP analysis.

1. Proposition: With the help of the MLP, the scientific situation of the dynamical phenomena as well as the level and unit of analysis can be specified according a unifying research frame.

The MLP suggests conceptualizing the case as a transition in a socio-technical system. The boundaries can be delineated by focusing on the socio-technical function housing. The framework also defines the situation specific unit of analysis a priori in a common language. The unit of analysis consists of different elements of the socio-technical housing system: Actors, (interaction)-rules, system resources (i.e. capacities) and artifacts (ee housing units) as well as multi-level and regime internal alignment processes. In addition to the scientific situation, also the relevant cognitive community and their communication channels can be identified (e.g. scholars of the Sustainability Transition Research Network).

2. Proposition: The MLP perspective helps to identify the thematic reference-authorities that are important to legitimize the scientific contribution of the simulation experiment for theory building.

The theoretical comparison of the applied FBP and the MLP builds confidence that the simulation experiment is an adequate case for replication or extension of MLP theorizing. It also suggests that the simulation approach is predetermined to discriminate the effective mechanism from a number of potential mechanisms explaining diffusion of ee housing units or path dependency. Hence the expected contribution would be to explicitly identify the causal circularities, and their directionality (balancing or reinforcing) based on relevant empirical evidence. Therefore the re-interpretation of the simulation experiment allows addressing theoretically derived research questions that may help to replicate or even to enhance theory building of the MLP. The two main research questions of the MLP can be discussed. RQ1: How does radical innovation emerge? RQ2: What mechanisms create stability and incremental innovation?

The RQ1 is mainly answered by the exogenous input variable exhibited in the CLD (Figure 4). At the one hand there have been landscape pressures (Oil crisis and climate change threads) that helped trigger dynamics in both the market niche as conceptualized by Levinthal (1998) and the technological niche as differentiated by Markard and Truffer (2008). In addition, the landscape pressures also triggered the differentiation of regulative rules of standard setting and governmental authorities, as well as the normative and cognitive rules of the supply and demand actors. The oil shock provided a window of opportunity for innovators within the value creation chain and the standard setting authorities.

The response to RQ2 addressing the identification of causal mechanisms creating stability and innovation is given by the endogenously explained changes of critical system states. The actions of the innovators within niche specific actor networks started to change critical system states that helped to enforce alignment processes. These have been described be the reinforcing and balancing causal mechanisms. The critical causal mechanism driving the alignment processes of user preferences have been captured by

the mechanism <Acceptance dynamics>. Those of the construction industry have been mapped by the mechanisms <Learning by doing>, <Market pull> and <Economies of scale>. Within the technology regime the mechanism <Technology push> is decisive while in the regime of policy and culture <Sliding goal setting> and <Limits to reduction> came into play and have created the path dependent ee improvement trajectory within the socio-technical system. Accordingly path dependency has evolved due to the random event at the landscape level (i.e. “oil crisis”) early in the history of the socio-technical housing system that has determined the observed transition path.
The ee improvement trajectory and its pace is dependent on five system states: ‘Energy demand of the innovative standard’, ‘Energy demand of the building code’, ‘Experience base with ee housing technology’, ‘Installed base of ee housing units’, as well as ‘Relative capacity to construct ee housing units’. These stocks as well as implementation delays have created system inertia, while the strong goal-seeking behaviour of the mechanisms <Technology push> locked the socio-technical housing system into the energy-efficiency trajectory even in phases of low energy prices.

> 3. Proposition: The MLP helps to specify the scientific task of theorizing, i.e. the formulation of theory based research questions and hypotheses. The expected contribution of the simulation experiment regarding replication and refinement of existing propositions can be postulated at an early state of the research project. Likewise the results of the simulation experiments can be reinterpreted in light of MLP theorizing.

The simulation model development process has been based on best System Dynamics modelling practice – with high efforts. However, expertise development in socio technical transition modelling requires that empirical rigor as well as parsimony of the simulation model needs to be balanced better. The MLP can become helpful in the development of theory based empiricism for simulation experiments in the sense that the data collection process can be focused on analytical concepts that have been defined in advance by the MLP. Also mathematical building blocks for the MLP concept may facilitate the formulation of further simulation models. Therefore methodically research within the MLP field needs to be developed. For example, the case specific simulation model illustrated in this paper could be simplified towards generic MLP model structures. This would allow its application for, testing and refinement with further socio-technical transition tasks.

> 4. Proposition: The MLP helps to develop expertise in simulation experiments of socio-technical transition challenge.

These four propositions postulate how the MLP would help to position System Dynamics simulation experiments as an applied modelling discipline in the field of socio-technical transitions. They also support the theoretical derived insight of chapter 2 that the MLP would provide a helpful descriptive term frame that enhances simulation experiments in various research phases.

4.2 What is the value added and limitation of socio-technological simulation studies?

While the discussion of the case study has provided evidence on a beneficial one directional influence of the MLP on simulation experiments up to here, this view is expanded to a bi-directional view in the following. The value added and limitation of simulation experiments for the enhancement of the MLP will be elaborated. The MLP can be characterized as a narrative and descriptive conceptual model that is missing causal explanation power.

System Dynamics practice provides scholarship on how to systematically reduce empirical complexity into a causal conceptual model towards a rigorously formulated simulation model. It helps to differentiate between exogenous variables that should be considered for the simulation experiment and those that can be excluded. It distinguishes exogenous modelling inputs from endogenous causal circularities that explain alignment processes. While descriptive MLP studies help to identify possible mechanisms that may explain the transition, simulation experiments and model analysis allows identifying most effective causal circularities with their polarities. As we have seen in the CLD, the mechanism scheme can be made explicit and detailed. Also the interactions between niches, regimes and landscape variables can be analyzed. Therefore simulation experiments - as illustrated above - can be seen as a response to the quest for logical precision (c.p. Geels 2010). Often used terms such as determinants, mechanism, circular causalities and accumulations can be concretized by the analytical concepts applied in System Dynamics practice. Also the formalization of core concepts such as path dependency can be mapped and analyzed more specifically. In the case study, the structure explaining path-dependency have been identified and tested in simulation experiments. Further on, simulation experiments may be used not only for theorizing on socio-technical transition but also for testing effective policy packages for reaching environmental policy and sustainable energy and CO_2 emission levels.

5. Discussion and conclusions

This study set out to reflect on the choice of adequate starting points for problem oriented simulation studies on transitions towards “greener” economies. Specifically, the MLP as a promising reference frame has been explored. Initially the FBP of the System Dynamics field has been chosen for a simulation experiment in order to shed light on complex interactions between behavioural and contextual factors. In the course of the simulation experiment affinities to the MLP became evident. The present study therefore has evaluated the potential of the MLP to push thinking on the simulation experiment beyond the initial FBP and to support theorizing in the sustainability transition field. The results confirm that additional value and insights from the integration of both perspectives can be gained. First the legitimacy and generalization of the simulation study can be enhanced since inter-subjective theorizing within a thematic reference authority is facilitated by the field of sustainability transition. Also, the MLP can become instrumental for the advancement of expertise in setting up simulation experiments that are focused towards the elaboration of generic small models on sustainability transitions. Second, the FBP and System Dynamics modelling, is most supportive for an operational and quantitative application of the MLP. Specifically, simulation experiments provide the opportunities to elaborate the MLP towards a causal process theory on sustainability transitions.

We have seen that the insights of the simulation experiment corroborate basics assumptions of the MLP concerning multi-level alignment processes. In addition, the insights of the simulation experiments can be re-interpreted as a transformation path, where niche innovation still needed to be improved in order to provide a satisfying solution to landscape pressures. Consequently regime actors have responded by modifying the direction of the development path and their innovation activities in niches (Geels and Schot 2007). In addition the case specific simulation experiment has highlighted the explanatory power of the innovativeness concept (Rogers 2003 5th Ed.) based on empirical data.

But the simulation experiment also adds some precision concerning the identified mechanisms moderating the alignment processes. Specifically the system specific condition of radical innovation and the creation of path dependency have been substantiated by causal mechanisms for the specific case. In addition, accumulations i.e. concrete state variables and adjustment delays have been identified as the determinants of system inertia. Only the co-evolution of these state variables within the socio-technical housing system made stronger ee standards for the mass market feasible. This actually supports the statement about socio-technical transition frameworks as third best policy approaches, which add realism to sustainability transition policy emphasizing social-political feasibility (Van den Bergh, Truffer and Kallis 2011).

In contrast to previous research on crossover between different research perspectives (Geels 2010) this study suggests that system theoretically founded frameworks such as the FBP may be useful to better operationalize the MLP. Accordingly, simulation experiments based on System Dynamics modelling may be one response to critics that asks for more rigorous and quantitative analysis approaches at both empirical and theoretical levels (Malerba 2006; Genus and Coles 2008; Markard and Truffer 2008).

> “The challenge for research here is to go to a much finer analysis, and to move from the statement that everything is coevolving with everything else to the identification of what is coevolving with what, how intense is this process and whether indeed there is a bi-direction of causality” (Malerba 2006:18)

Further experimental simulation studies are needed to differentiate further alignment mechanisms as well as transition pathways. The result of such a research avenue could be a typology of generic model structures or small models that explain different transition pathways. Such an endogenous explanation of radical innovation and sustainability transitions rank also high on the list of empirical desiderata in innovation research (Ahuja, Lampert et al. 2008). In their literature review on determinates of innovation they recognize that from a firm perspective many determinants of innovation have been identified in the past but that relatively little is known about radical versus incremental innovations (the quality of innovation) and its generation process. Also the problem of establishing causality remains. “Endogeneity of the key regressors is an unfortunate problem that bedevils much of the work on innovation” (76). Therefore they conclude

"Innovative research designs and the use of context that permit causal identification rank high on the list of empirical research." Also Hedström and Ylikoski (2010) emphasize the importance of explanation approaches in philosophy of science and social science that are based on causal mechanisms.

For the development of expertise in sustainability transition modelling the choice of the adequate starting point remains critical. While the MLP has proven its adequacy for the selected simulation task, further transition frameworks need to be considered depending on the concrete problem definition (e.g. Bergek, Jacobsson et al. 2008; Safarzynska and Van den Bergh 2010). However, the ultimate utility test of such an integrative transition modelling approach would be the analytical power to deduce testable policy recommendations for socio-technical transition challenges.

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