On the Design of System Transitions

Is Transition Management in the Energy Domain Feasible?

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***Abstract*—The primary objective of Transition Management appears to be 'to manage transitions towards sustainability.' The emerging body-of-knowledge on system transitions to date remains largely descriptive, however. We propose a research agenda to develop a prescriptive system transition body-of-knowledge, which eventually will provide handles for policy makers to push and pull transitions. This agenda is developed by focusing on energy systems. We conjecture it is always socio-technical systems that are the subject of transition. *We define a system transition as a structural change in both technical and social subsystems.* We conclude that shared definitions must be developed of indicators of sustainability performance of systems in transition. Secondly, an understanding and recognition of the socio-technical design space is required. The design space for energy systems includes technological structure and content, policy, regulation and market design and social innovation. The combination and interrelation of these must be recognized and its use suitably underpinned, for example by exploratory simulation models and games that would allow ex-ante testing of transition policies and management.**

***Index Terms*—System transition, Transition Management, Simulation Modeling and Gaming, Energy**

I. INTRODUCTION

TRANSITION Management appears to have as primary objective 'to manage transitions towards sustainability [1, 2]'. Geels states: "In recent years, there is increasing interest in transitions and system innovation, because of their promise to achieve jumps in environmental efficiency" [3]. Indeed, environmental efficiency of energy systems with respect to SO_2, NO_x, soot and other harmful emissions has dramatically improved in the past decades. Meanwhile, in energy infrastructures, exhibit only gradual and limited improvements of system performance with respect to CO_2 emission - through technological progress energy systems are slowly approaching the theoretical conversion efficiency limits set by the Second Law of Thermodynamics. Through system innovation, these limits sometimes are relaxed or avoided by clever combination of the generation of heat and electric power [4].

Generally speaking, the demand for energy is determined by population P, per capita demand A and technological characteristics T, which leads to an impact I as according to the well-known equation $I = P \cdot A \cdot T$ [5, 6]. Reducing energy system CO_2 impact thus implies a change of population, technology and/or in demand per capita. Today, the need a reduced CO_2 impact is clearly stated and acknowledged by many governments, i.e. by setting targets for GHG emission reductions [7, 8] by means of the Kyoto protocol [9] and through post-Kyoto measures. In the Netherlands, for instance, transitions are explicitly addressed in energy policy [10-12]. We conjecture that only by structural change, system innovation of the energy infrastructure the long-term goals of 20, 30 of maybe 50% CO_2 emission reduction can be met.

Having acknowledged the complexity of today's energy infrastructure, it is a huge challenge to reinvent and re-design this socio-technical system [13], let alone develop a program suitable for managing its transition.

The objective of this paper is to develop an agenda that addresses this challenge: how to design system transitions for energy infrastructure? First, key Transition Management literature is summarized. Subsequently, a socio-technical systems perspective is introduced and adopted. Finally, using this perspective and energy infrastructure knowledge and knowledge of design and design processes, the design of system transitions is explored to develop a research agenda for a prescriptive system transition body-of-knowledge.

II. OVERVIEW OF TRANSITION (MANAGEMENT) LITERATURE

Transitions can be defined as "gradual, continuous processes of change where the structural character of a society (or a complex sub-system of society) transforms" [14]. Societal transitions are defined as "structural innovations of societal systems in reaction to wicked problems threatening development" [1, 15].

Transition management can be summarized in the following characteristics [14]:

- long-term thinking for framing short-term policy;
- multi-domain, multi-actor, multi-level;
- focusing on learning;
- aligning system innovation and system improvement
- keeping a large number of options open.

Presently, how transitions emerge is conceptualized in two ways. First, literature on transitions uses three analytical and

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heuristic levels for system innovations [16]. The micro-level contains technological niches, in which new technologies can come into existence and be developed. The meso-level holds a patchwork of regimes in a dynamic equilibrium. The macro-level contains socio-technical landscapes, with global and normally slow developments. In this formalization, transitions occur when novelties on the micro-level evolves and is taken up to modify the patchwork of regimes and eventually transforms the landscape on the macro level [3]. Several papers and books have been using this conceptualization to describe and analyze past transitions [1, 2, 17, 18].

Second, four transition phases are identified in the pathway of transitions [14] (see Fig. 1). A phase of predevelopment (1) is one of dynamic equilibrium. In the take-off phase (2) change starts to occur. During the breakthrough phase (3) visible structural changes take place. A transition ends with a stabilization phase (4), where speed of change decreases and a new dynamic equilibrium is reached. Three system dimensions are identified, given a(n) (set of) indicator(s): the time period of a transition, the speed and the size of the change.

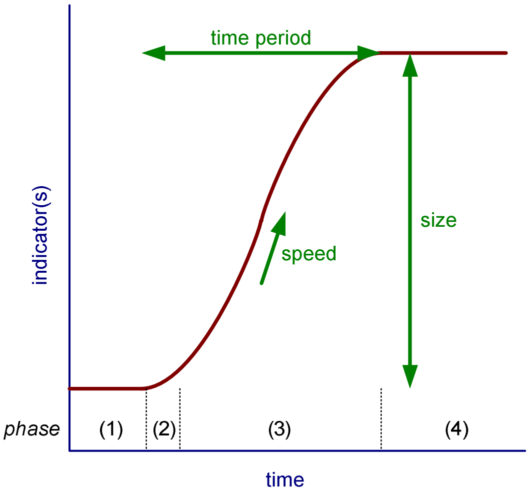

Fig. 1. Phases and indicators in transitions, adapted from figures in [14].

III. LARGE-SCALE SOCIO-TECHNICAL SYSTEMS

Policy makers face the challenge to design policy in large-scale socio-technical systems (λ-systems) [19, 20]. These infrastructures contain many interdependent components: many different actors having specific goals and means to reach them, and technological subsystems with limited capabilities. λ-systems are evolutionary, they exhibit path-dependency; options in the future are shaped by current choices as well as current options have been shaped by the past. As a consequence, λ-systems were not designed as they are now but evolved to their present state [13, 21]. Technological components are not necessarily equipped to meet modern needs, in terms of sustainability, reliability, flexibility and this impacts the policy design process. Increasing the complexity of that job, changes in technical components of λ-systems often have to go through changing actions of stakeholders. One cycle of new policy design, over time resulting in an improvement in the system could be a system transition if the total system would have structurally changed (see Fig. 2).

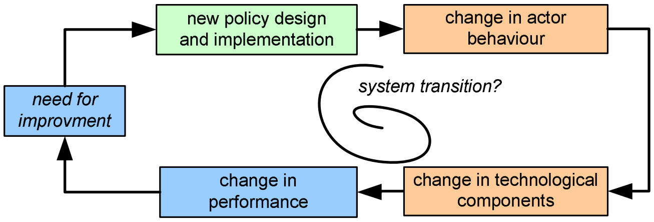

Fig. 2. From policy design to a change in performance in λ-systems.

The eventual societal goal of transition management (TM) research is to accommodate policy makers to manage a transition in sectors for which it is identified that structural change is needed. One can argue whether gradual and/or continuous change is required for such a transition. In addition, we believe that transitions are not only to be used as reaction the wicked problems threatening development. Therefore, we stretch the definition of transitions and societal transitions to a definition that is more on systems thinking. Therefore we will use a definition for system transitions (see also Fig. 2): *a system transition is structural change in both technical and social subsystems.*

The energy infrastructure is clearly a λ-system: actors have been liberalized and competitive tasks (power and natural gas generation and retail services) were unbundled from monopolistic tasks (grid and pipeline operators); the sector is embedded in and strongly connected to several markets, i.e. fuel, emission-trading and spot markets. All the actors active in these markets have their own objectives to realize their objectives and means to do so. And the government has to set the rules of the game, with policy and regulation as main instruments, in such a way that actors by realizing their goals will have optimum behavior according to the policy makers set of objectives. For the energy domain, *managing* a system transition implies the design of energy policy and regulation that invokes change by influencing the actions of stakeholders that in the system are in control of energy technology.

IV. BUILDING BLOCKS FOR SYSTEM TRANSITION DESIGN

The design of complex systems is different to a simpler systems [22, 23]. It is a process [13]. In order to come to a design a system transition, we use the conceptual model of a design process (See Fig. 3). The main steps in a design process are development of goals, objectives and constraints, the design space and tests. By executing tests the best performing design is selected for implementation. In this section, the design process is applied to systems transitions.

A. Develop goals

The first step in the design process is the development of goals. In the end, the design must be selected that fulfill these goals the best. Therefore, goals should be unambiguous and complete. In order to develop the goals for a system transition, transition managers involve many actors: it is a multi-actor process. In addition, TM claims it is preferred to state ambitions above objectives and rather qualitative than quantitative ones, all together subject to re-adjustment. In design approaches, goals are formulated as functional requirements, must-haves and should-haves.

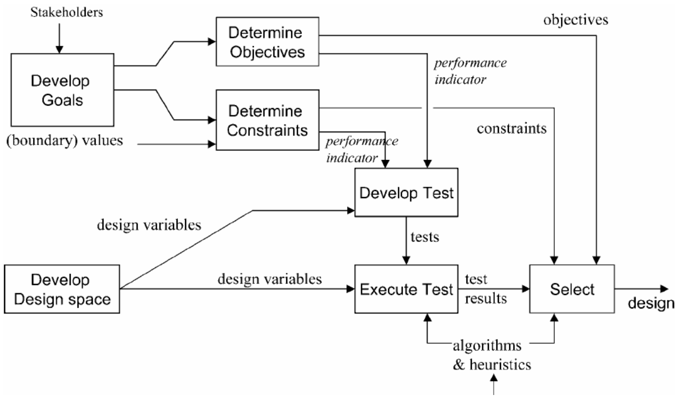

Fig. 3. Conceptual model of a design process [13].

For system transitions in energy, transition managers claim as main functional requirement that the energy infrastructure should must be sustainable [2]. This goal only reflects what the outcome of transition should be. A proper design of a system transition for energy should contain functional requirements for the system transition itself. In addition, sustainability is an ambiguous concept. Finally, it cannot be expected that all involved actors agree that sustainability is the only goal. Other actors have different goals in this design process and since they are involved, they will impact the goals resulting from this step.

B. *Determine objectives and constraints*

In determining objectives and constraints one makes explicit the previously defined goals. For all objectives and constraints performance indicators are identified whereby one can assess whether and to what amount the objectives and constraints are met. This is necessary to be conclusive on the performance on different designs of system transitions. Actors will put in effort to make sure that for them relevant objectives and constraints are put in or left out according to their own preferences and means.

Two notes should be made here. First, designing λ-systems result in a huge set of constraints and objectives, possibly including conflicting ones. That would trouble defining the design space. For the design of a system transition this might be even more problematic, because not only the socio-technical system but also the transition process is subject to objectives and constraints. Second, objectives and constraints must result in measurable performance indicators. Indicators identified for system transitions are based on a top-down systems view as mentioned in the second section: the time period of a transition, the speed and the size of the change. However, one could identify many more by analyzing what the characteristics of a transition pathway means for the socio-technical system in which the system transition occurs. The only explicit and measurable performance indicators for the socio-technical system as a whole are emission levels for a series of substances (e.g. CO_2, NO_x, etc.).

C. *Develop the design space*

Crucial in any design process is the development of a suitable design space. A design space is build-up from design variables that can be varied in order to come to the set of possible designs. A design space may be n-dimensional.

The multi-level perspective [3] and the four phases in a transition [14] structure how transitions come about. The key point in the multi-level perspective is that system innovations, that lead to system transitions come about through the interplay between dynamics at multiple levels. Design variables should therefore impact the dynamics on those levels. The four phases imply that transitions follow a certain pathway. Designing a transition therefore implies designing this pathway and according to that design variables to do so. This transition path is however directly connected to indicators (recall the vertical axis in Fig. 1): for the identification and use of transition pathways, unambiguous and measurable performance indicators are a necessity. Both perspectives do not focus on how impact system transitions and are rather equipped for analyzing and describing past transitions.

Design variables rather come from transition management (TM) literature: methods for invoking transitions might be useful as design variables for system transitions. The transition instruments discussed here [14] are:

- transition objectives;
- interim objectives;
- transition visions;
- evaluating and learning
- creating public support.

Transition objectives and interim objectives rather belong to developing goals (and after that determining objectives and constraints) then being design variables. (Note that they were discussed earlier at those sections). Transition visions are also not part of the design space, because they are a means to explicate and visualize the end result of a system transition. However, these far-future visions can be used to derive transition steps that can lead to that end result. Next, by creating public support (through the involvement of actors in decision-making and through education) in the process one can create a momentum for change. That also relates more to earlier parts of the design process, i.e. determining objectives and constraints. Final is that by supporting technological niches innovative concepts can mature and, if successful, diffuse into society.

Rotmans [14] states that TM uses a systems approach: “The system approach implies thinking in terms of stocks and flows”. And therefore “a transition is the result of long-term developments in stocks and short-term developments in flows.” … “During the quick period of growth, acceleration is mainly the result of positive feedback mechanisms”. This top-down view is of course useful but just one side of the story. Complex systems and complex adaptive systems theories tell us that change in λ-systems is the aggregate result of decisions and actions by individual entities. We therefore argue that it is disaggregate actions of actors that should be the focus of transition analysis, rather than the regime in order to come to a design of system transitions. For instance, CO_2 emissions occur on a disaggregate level: an increase in the CO_2-concentration in the atmosphere is the result of many smaller and larger sources in which (for the part that mankind is responsible of it) control of these sources is by many different actors. This conceptualization has consequences for the design space for system transitions and can enlarge it dramatically by including design variables that impact these disaggregate decisions. However, one must note that the successfulness of deriving design variables is interdependent with the identified set of performance indicators.

D. *Develop and execute tests*

All possible combinations of options for variables within the design space are potential alternatives that can be selected for implementation. If performance indicators are defined well, i.e. when they are measurable and unambiguous, it is possible to develop and execute tests that can grade the performance of the design alternatives. Designs for system transitions can not be tested in reality: only one test could be executed, afterwards the system was changed by the test itself. As a consequence, the TM literature is thick on historic cases. Best practices are identified analogous to those cases, rather than identifying design alternatives and test beds for them. For real testing of design alternatives one can use the power of modern computers to imitate real systems in simulations. In those simulations, all essential components of the socio-technical system should be apparent. Simulation exercises need to be well focused and have tailored designs to come to results that are meaningful. This especially true for models on system transitions, since the λ-system under study have many relevant components and are heavily connected to other systems. Relevant components include the technological system of apparatus and connections, the preferences of stakeholders and their social and economic behavior, and policy. Simulations can be used to better understand the functioning of λ-systems, to explore and identify determinant components and their interplay and, what for this section would be its main aim, to test the impact of design alternatives without implementing them. This can all be done without having the ambition to predicting the future, rather predicting the variety of trajectories and future states for a λ-system, given a set of well-chosen assumptions. To enrich the codification process of actor behavior, one can use serious gaming. By observing the outcomes and motivations of real players in a serious game, one can extract actors' behavior and translate it to real situations. With these simulations and games, one can execute tests for design alternatives and gain their performance on the defined indicators.

E. *Select*

The selection is made based on the outcome of the executed tests. If the performance indicators are well defined and the tests well developed, than one find out what design alternatives meet all constraints. Those are still feasible. If there is more than one design alternative left, one can select based on the objectives. Comparing objectives is subjective and it is probable that actors weigh the objectives differently. Selection for a design of a system transition therefore might prove very difficult. However, in that selection process indicating the performance of alternatives is crucial, so that a fair selection based on a discussion on objective importance becomes possible.

V. CONCLUSIONS AND OUTLOOK

A design of a system transition should lead to the optimal structural change by taking the preferred transition pathway in a λ-system (See Fig. 4). The complexity in the energy infrastructure shows in difficulties in designing system transitions in the energy domain. In order to an optimal design of system transitions, a process design approach should be used and three issues are identified in applying such an approach. Those issues are on the research agenda.

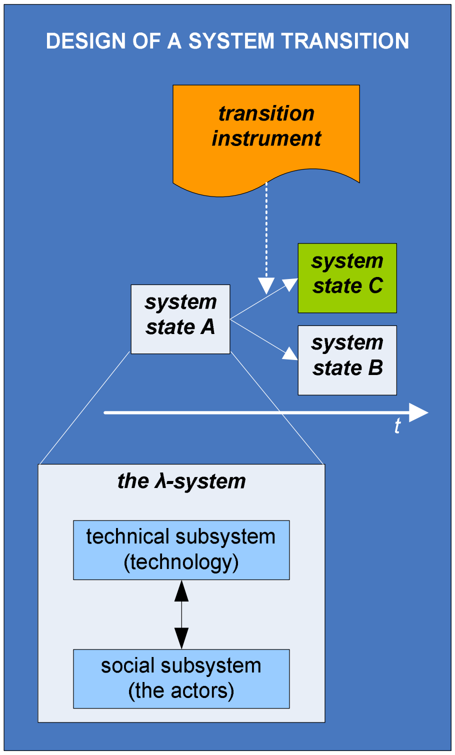

Fig. 4. Design of a system transition.

The first, issue on the agenda is related to system performance indicators. Since design teams need to assess the characteristics of their designs, the goals must be made explicit as objectives and constraints for which measurable performance indicators can be defined. As argued in the previous section, in transition management literature such performance indicators are lacking or ill-defined, which leads to and obvious research agenda item: research on developing shared definitions of and performance indicators of system transitions. With such definitions, one can assess when a system transition is started and completed and whether it can be called a system transition, effectively share this information and over time create a body-of-knowledge on what works and what does not work for transition management.

Second, design variables for system transitions in the energy domain should be discovered by using insights in technology, policy and economy from literature on system transitions, design, complex systems thinking, energy technology and energy policy. Transition instruments should be identified to come to feasible designs

Third, tests should be developed whereby different system transition designs can be compared. We argued that simulation models and gaming are needed as tools to compare the performance of different designs. These tests should contain relevant elements in the λ-system under study by incorporate the interdependency of technology, policy and economy.

We believe that proper design of system transitions is a necessity to achieve a less carbon intense energy infrastructure. This requires new policy, law and corporate strategies. To provide decision support for better policies and strategies, we developed a research agenda for a body-of-knowledge on system transitions that is prescriptive, which will underpin transition management for sustainability.

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