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# No way out? – Analysing policy options to alleviate or derail Success-to-the-Successful in the energy system

A. T. C. J. Dangerman<sup>\*†</sup> & A. Größler<sup>‡</sup>

## Abstract

The purpose of this paper is to briefly discuss the presence of the archetype “Success-to-the-Successful” in the energy system and to analyse policy options in the presence of this archetype in the energy system. More precisely, the paper aims at finding conditions under which the path dependent allocation of investments directed to the conventional energy-technology sector can be alleviated, in order to encourage investments in alternative energies and technologies. The discussion draws on a stylized and highly aggregated model of the energy system, which is based on system dynamics. Sensitivity analyses are used as the major diagnostic tool to identify options to break away from the current dominant path of energy production and use, and the investments made in it. The value of this paper lies in the clear articulation of a complex and fuzzy topic, with the help of modelling and simulation. Implications for research comprise a further elaboration of the simulation studies within the energy field.

Keywords: energy, policy making, investments, path dependence, “Success-to-the-Successful”, lock-in.

## 1. A systemic perspective on the energy system

If one considers the widely accepted economic free market theory and the fact that it is widely assumed to solve the problems of the energy system (excessive CO<sub>2</sub> production, air, water and land pollution, geo-political stress, rising food prices—induced by biomass production), one wonders if and when these problems will indeed decrease in their size and impact. In the light of this question, an exploratory study of the energy system with a particular interest for the presence of path dependence and lock-in traits has been conducted (Dangerman, 2011). The main finding is that the energy system exhibits behavioural structures similar to the system

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dynamics archetype “Success-to-the-Successful”. The study shows the prevalence of sources and characteristics of path dependent behaviour throughout the energy system that lead to—despite public and political claims of a free flow of capital—a perseverance of historic “successes” of certain energy sources and associated technologies to the possible detriment of chances of competing alternatives. In that study, literature research, data collection, interviews and dialogues with energy experts, and participative (qualitative) modelling were used as methods for gaining insights. In this paper, first attempts are presented in quantifying parts of the energy system by modelling and simulating this issue with system dynamics.

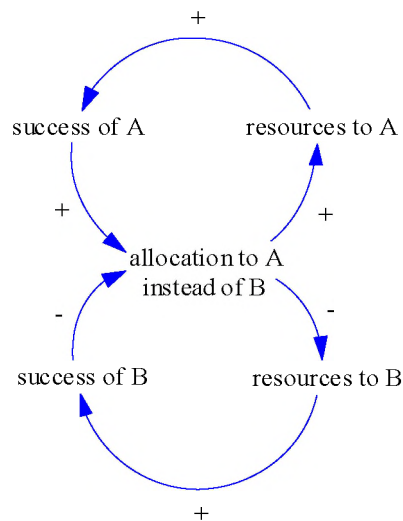
In this paper, the term ‘energy system’ is used in a broad sense and includes the following forms of energy sources: oil, coal, natural gas, nuclear and biomass, solar, wind, geothermal and hydro energy. The technologies that are involved in the generation and use of these forms of energy are taken into account. The various forms of energy and their accompanying technologies are classified in two groups: a conventional energy-technology subsystem (which includes oil, coal, natural gas, nuclear and biomass, and the accompanying technologies) and an alternative energy-technology subsystem (which includes solar, wind, geothermal, hydro energy and accompanying technologies). In addition to conventional and alternative energy-technology, the energy system that we look at in this paper contains a financial subsystem that generates the monetary resources necessary to build-up and to maintain energy production and distribution facilities. Obviously, this definition of the energy system is non-exhaustive (for instance, we do not extensively consider an environmental subsystem or a political subsystem in this paper) since we limit our endeavours to testing policy options for breaking away from a path dependent situation, in which most investments in new energy-technology go to the conventional energy-technology subsystem. Thus, the purpose of this study is to analyse which policies can be helpful in breaking away from the current path of investments in highly profitable conventional energy and associated technologies toward going into an alleged non-beneficial area.

In section 2 we provide a brief description of the three individual subsystems of the energy system we mentioned earlier—i.e. the conventional energy-technology subsystem, the alternative energy-technology subsystem and the financial subsystem—and discuss path dependent behavioural structures of the energy system that create rigidity and lock-in. The third section presents a system dynamics model for policy analyses regarding the “solving” of this situation. In the section after that, sensitivity tests are presented that we use to derive

policy options. We conclude the paper with a discussion of outcomes, limitations and further research in section 5.

## 2. Path dependence and lock-in in the energy system

Mechanisms similar to the archetype Success-to-the-Successful appear to be operating between the two energy-technology subsystems with investment capital (from the financial subsystem and the conventional energy-technology subsystem) as the resources for which the two energy subsystems compete. One can observe the similarities between the basic structures of the energy subsystems and the financial subsystem as represented in the archetype Success-to-the-Successful (Senge, 1990; see Figure 1).



**Figure 1. The archetype Success-to-the-Successful (after: Braun, 2002)**

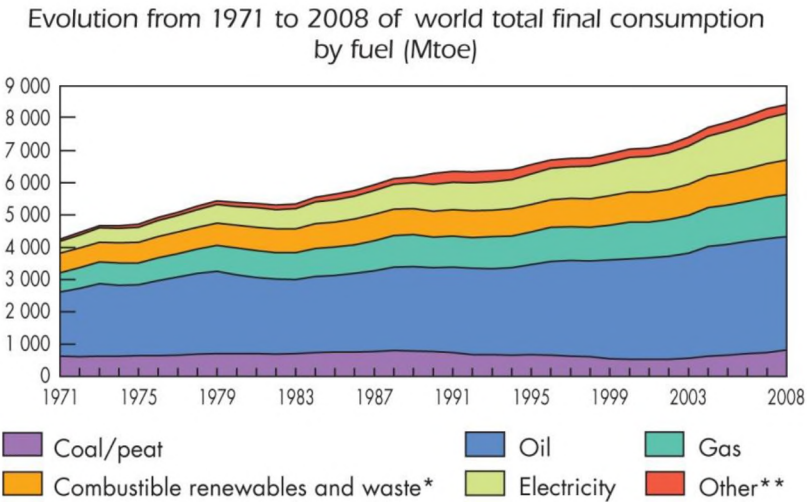
The mechanism underlying the archetype Success-to-the-Successful determines the allocation of resources to a party in reward of success to create even more success. At the same time, these (finite) resources are consequently not appropriated to another competing party, and such competitor is thus limited in its chances of success. This mechanism with initially multiple equilibria (in the beginning any of the competing parties can get the resources allocated to them), path dependence (success propagates success and failure propagates failure), and lock-in (once a more or less consistent allocation to either A or B has occurred long enough, changing allocation to the other party in this structure is virtually impossible) can also be characterised by a linear and non-linear Polya process (cf. Arthur, 1994). Success-

to-the-Successful may function as a powerful barrier to change. To cite Braun (2002, p. 12): “finding itself bogged down to this archetype can also lead to the erosion of innovation and change.”

When the archetype commences to operate, the allocation of resources to a subsystem A instead of allocation to another subsystem B, rather than the other way around, is still a feeble equilibrium and can—with small changes, such as an invention or new regulation—relatively easily be disturbed so that the allocation switches to B instead of A. However, the longer this mechanism is operating with A being successful and able to tap the resources competed for, the more difficult it will be not only for B to be successful but for any new market entrant with an interest for the same resources—reasons are high up-front costs, network effects, learning effects and self-reinforcing expectations are involved (cf. Arthur, 1988). Whether a new entrant, for example a new technology, may be technologically or economically superior to the dominant technology may not play a role in this division of market shares; historical choices and structures may cause the market to prefer other reasons than such superiority to invest in certain technologies. Nevertheless, the lock-in to a certain division of market shares and its possibly damaging characteristics, however persistent, are not permanent. Somewhere in the whole system, or in the variables present in the Success-to-the-Successful mechanism itself, eventually changes will occur (such as stocks being depleted or new technological competitors entering the system that do not need to compete for the same resources) that finally break down the existing lock-in structure. Given the progress of the problems of the energy system, the question is when such change is to occur and whether we have the time to wait for such a change to occur, without actively intervening. After all, to phrase Keynes (1923): “in the end we are all dead”. And he continues: “economists set themselves too easy, too useless a task if in tempestuous seasons they only tell us that when the storm is long past the ocean is flat again”.

In addition to the competition for financial capital from the financial subsystem and for subsidies and loans from government, the conventional and the alternative energy-technology subsystems are, whilst operating under increasing returns, also competing for the use and adoption of their respective forms of energy and accompanying technologies by customers (Dangerman, 2011). If a customer has bought and received the technology and pertaining energy he needed for a particular purpose such as fuel for a car or the heating system for the house and natural gas, he does not require alternative technology with accompanying energy for that same need, which has been satisfied. If a certain energy-technology combination has

been chosen by a group of users other competing energy-technology combinations are thereby—for some time (as we assume the demand for energy-technology is at least for a certain period of time finite)—excluded from adoption by this group of users, since these users’ demand have been fulfilled. In the event conventional energy-technology is adopted by consumers, the flow of money, pertaining profits and learning loops of both consumers and producers of energy-technologies increase, thereby diminishing the chances for the alternative energy-technologies of success. If one examines Figure 2 in this context it can be seen that from the point of view of the energy system and the Success-to-the-Successful archetype, out of these two competing energy-technology subsystems the conventional energy-technology subsystem is currently by far the most successful in having its energy consumed and pertaining technology adopted (and the shares between the energy technologies have not substantially changed throughout the period examined).



**Figure 2. World’s total final energy consumption from 1971 to 2008 (IEA, 2010)**

Finally, it is worthwhile mentioning a mechanism that governs the competition of individual beliefs and the social paradigm that eventually follows from those beliefs. On the one hand, the human brain has the tendency to snap to a single reality as understanding of complex situations are involved (cf. Scheffer & Westley, 2007), on the other hand, that same brain will, according to Hebb’s law, favour the line of thought or belief that has been ‘executed’ before over a new not-yet-executed line of thought or belief (Hebb, 2002). In other words: on an individual neuropsychological level of belief Success-to-the-Successful appears to be operative as well. The more we have gotten convinced of a certain belief and the more the

relevant parts of our brain have fired together, the more we appear to be convinced of such belief to the exclusion of possible other beliefs and the more these parts of our brain have gotten wired (and connected) together, as parallel competing beliefs are not necessarily what brains are designed for (cf. Hebb, 2002; Scheffer & Westley, 2007). If the individual beliefs scale up to a level of a paradigm through social interaction and through individually and collectively passing the loop of conviction, action and confirmation, to form—to put it in Capra's words (Capra, 1997, p. 6)—“the basis of the way the community organises itself”, the Success-to-the-Successful structure establishes itself on a societal level as well. Thus, in the energy system, managers, investors, politicians and consumers have long experienced positive outcomes in the form of profits, economic growth and product reliability from their conservative investment decisions. These outcomes were strengthening their beliefs and confirming the appropriateness of their individual and group decisions. Accordingly, the behavioural structures of Success-to-the-Successful appear to be not only present in the financial investment structures but also in the social fabric, i.e. on the level of the individual, the group and society, of the energy system as well (Dangerman, 2011). It seems undeniable that both Success-to-the-Successful mechanisms—that of individual or group conviction and consequential decisions and actions on the one hand, and that of financial investments and consequential returned profits on the other hand—are tightly connected and reinforce each other.

### **3. A system dynamics model of investments in the energy system**

Despite a long tradition of related work in system dynamics (Sterman, 2000, ch. 10, and the work cited therein), modelling and simulation have recently been identified as promising new methodologies for research in the area of path dependency (Vergne and Durand, 2010). Since the archetype Success-to-the-Successful is a specific form of path dependent processes, a deterministic simulation method appears appropriate to investigate the issue of Success-to-the-Successful further. The simulation model we use for further analyses focuses on the competition for (financial) capital from the financial subsystem by the two energy-technology subsystems, and leaves out the other potential fields in which Success-to-the-Successful was identified (see section 2).

Figure 3 shows a stock & flow diagram (Forrester, 1961; Lane, 2000) based on the conceptual understanding of the issues discussed in the first half of this article. The central chain (indicated by double arrows) represents the flow of capital from freely available (financial)

capital into bound capital (e.g., in the form of energy production facilities) in the two subsystems, conventional and alternative energy-technology. Between these stocks (indicated by rectangles in the diagram), flow variables are located (indicated by a valve symbol) that govern how capital flows from one stock to the other. These flows are controlled by information feedback loops that symbolize the decision-making process in allocating the (financial) capital. The flows determine what amount of capital flows either way and how long, on average, capital remains productive. Their value is dependent on a discrepancy between desired and actual capital for energy production and on an inclination to invest in one of the two energy-technology subsystems, conventional or alternative energy-technology. Together with the depreciation of capital, those two mechanisms form feedback loops (indicated by a circular arrow symbol).

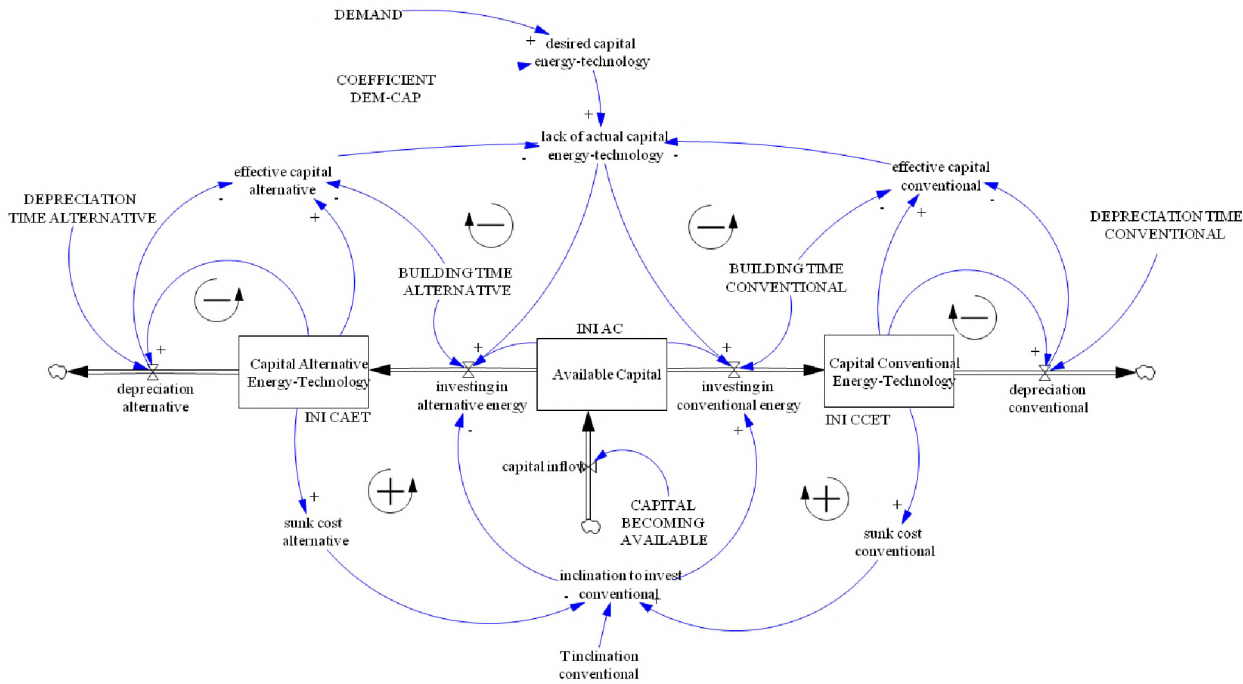


Figure 3. Stock & flow diagram of simulation model

The next step in modelling is the formulation of quantitative relationships between the model variables, in the form of equations and parameters. In the model it is assumed that the allocation towards one of the energy-technology subsystems depends on an inclination to or a preference for a particular subsystem, which is in turn based on investments already made and the sunk costs related to that. In other words, more capital is invested where much capital has



been invested in the past. This effect is controlled by a table function (*T inclination conventional*), that can be adjusted to represent different degrees of favouring the conventional energy sector over the alternative energy sector. An additional assumption in the model is that demand for energy is an exogenous parameter, i.e. its value is not influenced by model behaviour. All other values of variables are endogenously generated by the dynamics of the model. A model listing of the total model can be found in the appendix.

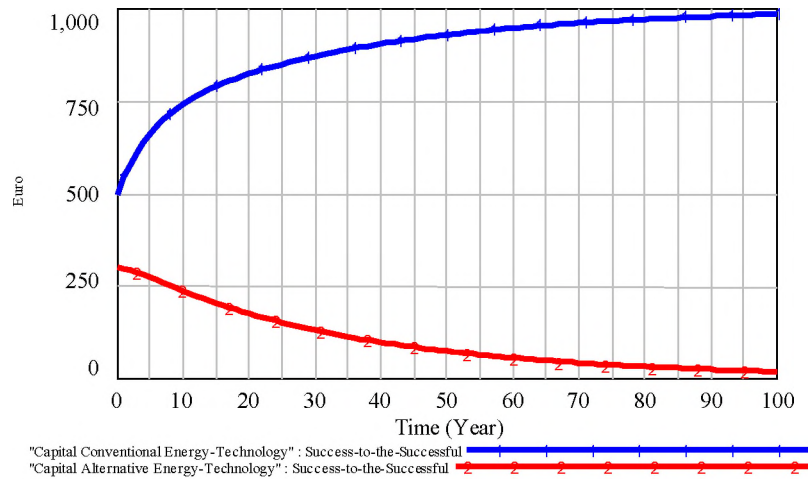
#### **4. Results of simulation runs**

The simulation model has been used to produce a variety of sensitivity runs to identify effective policy options, about which we report here. In all of the following simulation runs, illustrative numerical values have been used that do not necessarily represent realistic numbers from the energy system. For all simulation runs we depict the development of capital (i.e. facilities to produce and distribute energy) in the conventional and the alternative energy-technology subsystems.

The base run of our model is depicted in Figure 4 and mimics the classical “Success-to-the-Successful” archetype as discussed above. In this simulation, financial resources are infinite<sup>1</sup> and at the beginning there is a lack of currently available capacity compared to the demand for energy-technology (20% capacity is missing); the conventional energy-technology subsystem has an initial advantage over the alternative energy-technology subsystem (the relation between the two capital stocks is 5:3). The necessary investments in new production capital are characterised by “increasing returns”: the investment policy implemented here allocates over-proportional additional investments in that sector that has an advantage already (i.e. the conventional energy-technology subsystem due to the initialization of stocks). As one can see, now the conventional energy-technology subsystem dominates more and more, while the sustainable energy sector becomes increasingly irrelevant: the typical Success-to-the-Successful behaviour pattern.

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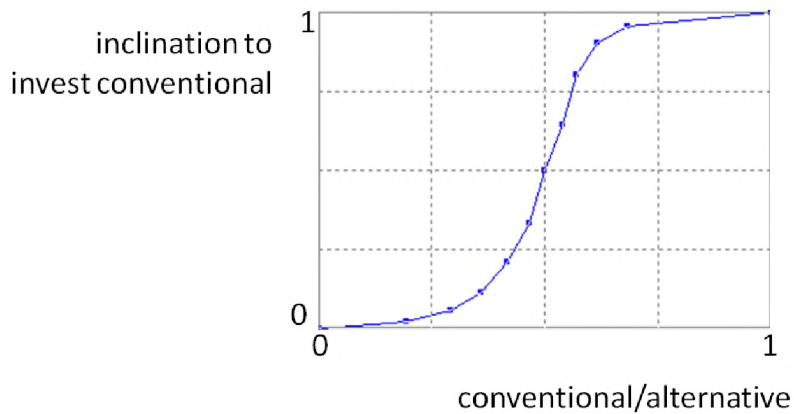
<sup>1</sup> Technically, in these simulations *capital inflow* exceeds the necessary investments by far.



**Figure 4. Base run: infinite resources, demand exceeds capacity BUT over-proportional reward to already invested capital**

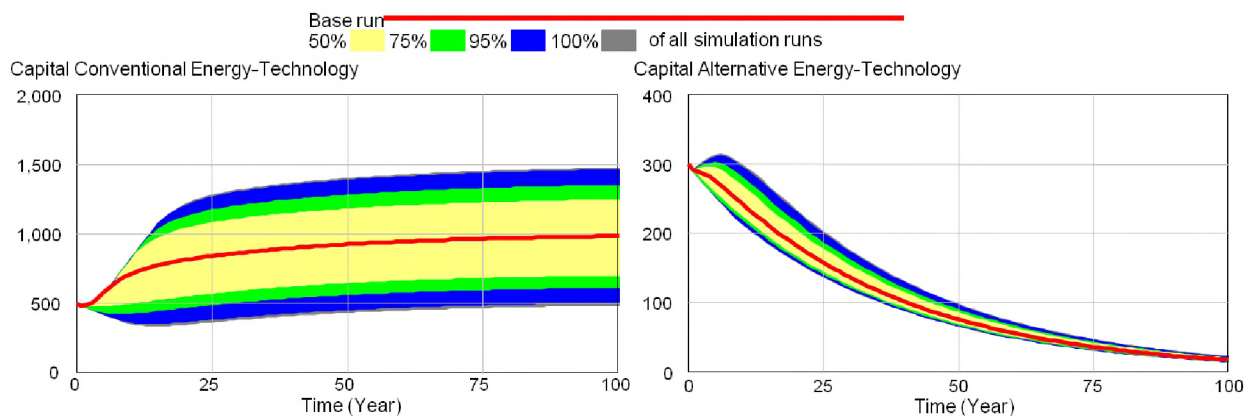
Figure 5 shows the shape of the lookup function that we use to determine *inclination to invest in conventional*. Various reasons can be considered to generate an over-proportional reward for existing capital. On the psychological level, investors might fall into a sunk cost fallacy<sup>2</sup> or are deciding based on availability bias. In terms of personality traits, risk averseness might lead to investing where capital is seemingly safer to invest. Economically, investments in sectors where fast returns can be expected seem beneficial. Moxnes (1992) argued that investments in conventional energy technologies may be caused by low cost and prices which are in turn created by learning curve effects. We want to emphasis here that we are not trying to explain why over-proportional rewards exist (for instance based on the phenomena just described); rather we assume them as given. Our aim with the simulations is to explore potential policies under this assumption.

<sup>2</sup> In an economic understanding of sunk costs, they should not be considered for decisions since they have already been written off. However, if we apply a behavioural understanding of the sunk costs bias, this bias makes decision-makers invest more when they already have substantially invested in a certain technology. Compare also “escalation of commitment”, Staw (1981).



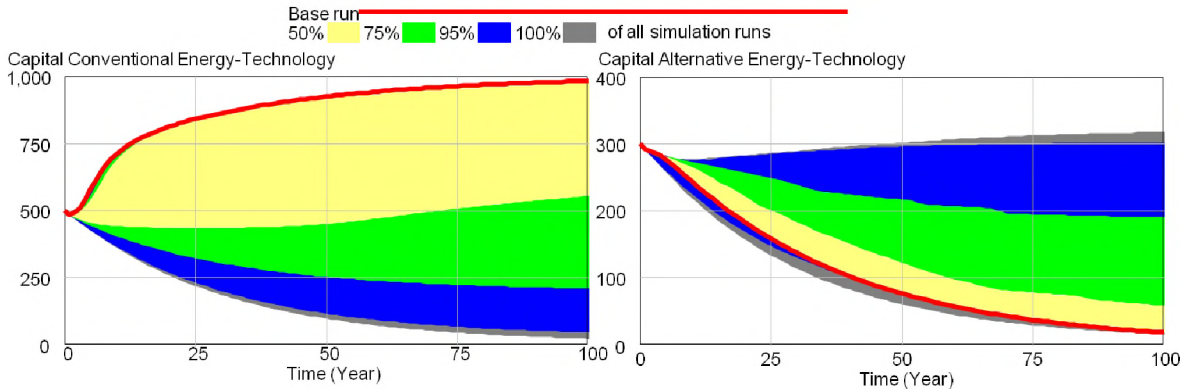
**Figure 5. Shape of table function that determines inclination to invest conventional**

The simulation results shown in Figure 6 depict the outcomes for a variation of the demand for new energy-technology (with the general settings as in Figure 4: initial advantage for the conventional energy-technology subsystem, over-proportional reward to already invested capital). The graph is a result of a sensitivity analysis that alters *Demand* between 500 and 1500, i.e. leading to situations of substantial over- or under-capacity with many intermediate scenarios. For basically all outcomes the base run behaviour from Figure 4 is more or less replicated (which is depicted by the red lines in Figure 6). Increasing demand does (naturally) not change the distribution of investments between the two sectors; in the case of heavy under-capacity, the alternative sector starts to increase as well but then the positive feedback loop with the over-proportional reward of the conventional sector kicks in leading to an ultimate success of the conventional sector.



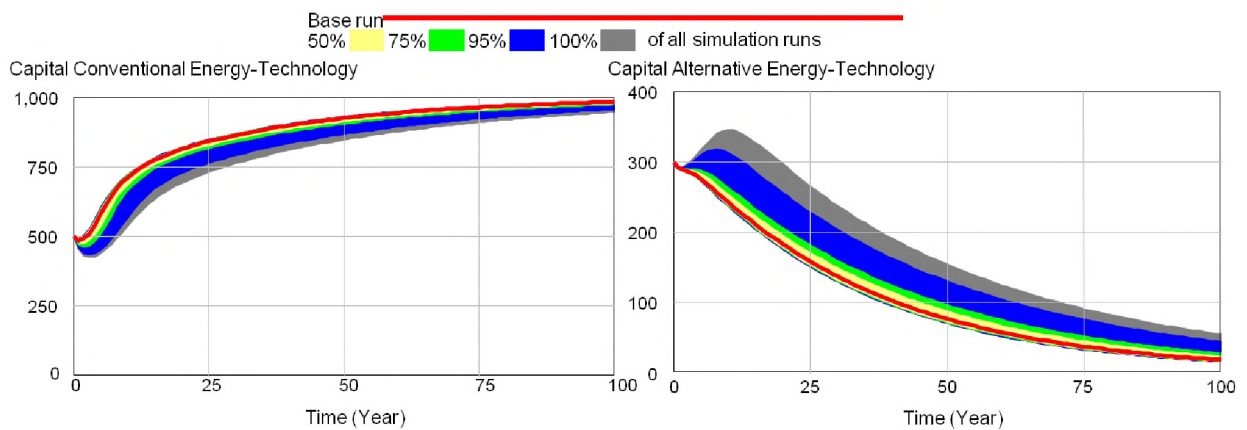
**Figure 6. Sensitivity analysis *Demand* [500; 1500], base case value 1000**

Figure 7 shows a sensitivity analysis, when capital is scarce and not virtually infinite as in the base run. Again, we have to realise that for most runs, the base scenario behaviour is replicated (showing a success of the conventional energy-technology sector). For some extreme cases, the alternative energy technology subsystems grows and catches up with its conventional counterpart despite its initial disadvantage and the over-proportional distribution of investments. The growth of the alternative energy technology subsystem can occur if (i) available financial resources are limited so that investments cannot fully account for exceeding demand but there is still some money available to invest (so, *inflow capital* is not zero) and (ii) due to the initial advantage of the conventional subsystem depreciations over-compensate additional investments in this subsystem, slowly shifting the advantage to the alternative energy technology subsystem. However, note that even in case of depreciations being larger than investments in the conventional energy technology subsystem, no complete transition to the alternative subsystem takes place; all that can be achieved in this model is that the subsystems become equal in size.



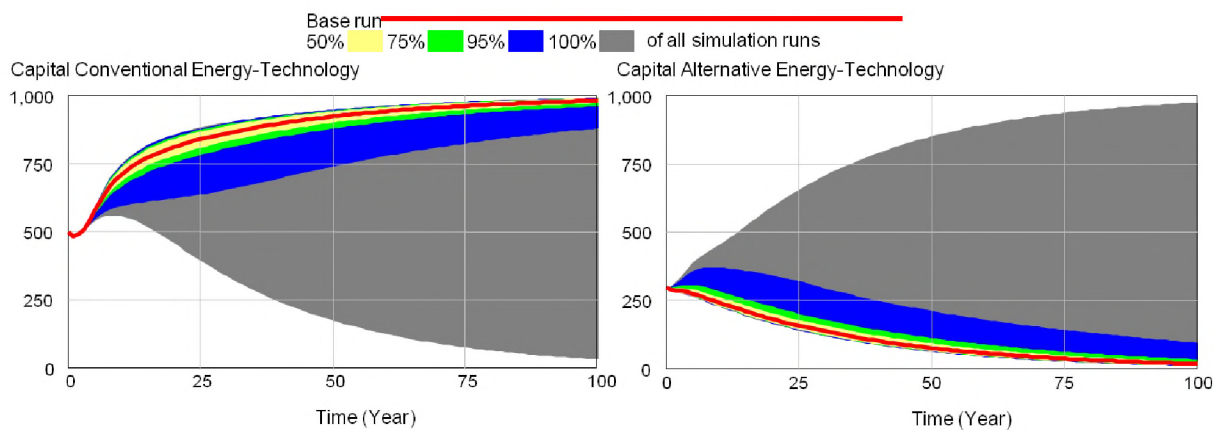
**Figure 7. Sensitivity analysis *Inflow capital* [0; 100], base case value 100**

Figure 8 depicts a sensitivity analysis that varies the depreciation time of the conventional energy-technology sector. Only shortening depreciation time for conventional alone does not change the behaviour of the system as long as the investment decision is based on past investments and there are unlimited resources: necessary re-investments are still made in the conventional sector. When depreciation time is really small, the conventional sector needs a while (with some losses and a parallel gain of the alternative sector) before it gains momentum again and finally, because of the over-proportional reward, succeeds.



**Figure 8. Sensitivity analysis *Depreciation time conventional* [10; 50], base case value 30**

The final sensitivity analysis shows at least a vague possibility, how the alternative sector could succeed, thus alleviating the rigidity in the energy system (see Figure 9). If alternative energy investments could be realised very fast, there is a chance to make the alternative sector the leading one (but only if the alternative sector is much faster than the conventional conventional in realising capacity) since then the alternative sector increases much faster than capacity is taken away by depreciation—a process that the conventional sector cannot cope with, despite the positive feedback loops working in its favour in the beginning.



**Figure 9. Sensitivity analysis *Building time alternative* [1; 10], base case value 5**

## 5. Conclusions

The purpose of our stylized and simplified system dynamics model was to identify policies or situations in which the lock-in of the energy system in conventional energy-technology can be alleviated. As our sensitivity analyses have shown so far, this is a rather intractable endeavour since for most parameter constellations the Success-to-the-Successful behaviour is retained. Within the range of parameters we set, only under very specific (probably quite unlikely but not implausible) conditions, the energy system could be changed towards favouring the alternative energy-technology subsystem: for instance, when the building time for alternative energy capacity can be lowered substantially in relation to the conventional energy capacity.

We argue that such conditions for change can only be achieved if an internal critical threshold is exceeded or exogeneous shocks strike a system that has become rigid as a result of its sustained path dependence. Joint actions were identified (cf. Moxnes, 1992) among consumers or government policies as measures that could reverse the Success-to-the-Successful pattern—however, quick changes should not be expected. In the example discussed in relation to figure 9, a combination of exertion of political power and an increasing demand of customers for renewable energy sources could reduce the building time for alternative energy capacity and, thus, could cause the system to break away from the path dependent situation. More extreme (but probably also more effective) measures could be a full scale prohibition of production of CO<sub>2</sub> (or other damaging output or consequences), the prohibition of investments in conventional technologies, or a complete stop of subsidizing conventional technologies.

Two extensions of this study come immediately to mind. First, a more realistic parameterization of the model can be employed; in particular, the initial value of the stocks of the two energy-technology subsystems are illustrative only (we used a 5:3 relationship in favour of conventional energy and assumed rather roughly that the demand for energy exceeds the existing capacity by 20% in the beginning of the simulation). Most probably, the relationship of capital bound in one of the two energy subsystems is much more biased towards the conventional subsystem, with the consequence that the breaking away from the trodden path is even harder to achieve. Second, we tested the variation of one isolated parameter in our sensitivity analyses. As a next step, we want to try combinations of these parameter variations. Furthermore, we are going to experiment with different lookup functions determining the inclination to invest based on past investments.

In a more general way, the model described in this paper can be used to investigate the following:

- How initial advantages in a system can be maintained under various environmental conditions;
- How initial disadvantages in one subsystem can be turned into an advantage in the long run;
- What are sensitive points for overall performance of the whole system and how overall performance can be secured;
- What externalities come with different situations, for instance represented by the pollution generated; in other words, what are the effects of different set-ups of the financial subsystems of the energy system on other parts of that system, for instance the environment or society (which have not been represented in the model yet);
- Why and how a system can be in lock-in, even though it is supposed to be open;
- What are conceivable decision rules of investors based on which the model is able to replicate historical behavior;
- What are possible interventions of regulatory bodies (like governments) to change the system.

The system dynamics model allows us to approach quantitative as well as qualitative answers to these questions.

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## Appendix: Model listing (equations in alphabetical order; illustrative parameter values)

absorption of pollution= $\text{Pollution}/\text{ABSORPTION TIME}$ ; Units: pollUnit/Year  
ABSORPTION TIME=100; Units: Year  
Available Capital= INTEG (capital inflow-investing in conventional energy-investing in alternative energy, INI AC); Units: Euro  
BUILDING TIME CONVENTIONAL=5; Units: Year  
BUILDING TIME ALTERNATIVE=5; Units: Year  
CAPITAL BECOMING AVAILABLE=100; Units: Euro/Year  
Capital Conventional Energy-Technology= INTEG (investing in conventional energy-depreciation conventional, INI CCET); Units: Euro  
capital inflow=CAPITAL BECOMING AVAILABLE; Units: Euro/Year  
Capital Alternative Energy-Technology= INTEG (investing in alternative energy-depreciation alternative, INI CSET); Units: Euro  
COEFFICIENT CAP-POL=1; Units: pollUnit/Year/Euro  
COEFFICIENT DEM-CAP=1; Units: Euro/GWh  
DEMAND=1000; Units: GWh  
depreciation conventional=Capital Conventional Energy-Technology/DEPRECIATION TIME CONVENTIONAL; Units: Euro/Year  
depreciation alternative=Capital Alternative Energy-Technology/DEPRECIATION TIME ALTERNATIVE; Units: Euro/Year  
DEPRECIATION TIME CONVENTIONAL=30; Units: Year  
DEPRECIATION TIME ALTERNATIVE=30; Units: Year  
desired capital energy-technology=COEFFICIENT DEM-CAP\*DEMAND; Units: Euro  
effective capital conventional=Capital Conventional Energy-Technology-(BUILDING TIME CONVENTIONAL\*depreciation conventional); Units: Euro  
effective capital alternative=Capital Alternative Energy-Technology-(BUILDING TIME ALTERNATIVE\*depreciation alternative); Units: Euro  
FINAL TIME = 100; Units: Year  
inclination to invest conventional=sunk cost conventional/(sunk cost conventional+sunk cost alternative); Units: Dmnl  
INI AC=1000; Units: Euro  
INI CCET=900; Units: Euro  
INI CAET=100; Units: Euro  
INI P=0; Units: pollUnit  
INITIAL TIME = 0; Units: Year  
investing in conventional energy= $\min(\text{inclination to invest conventional}*\text{lack of actual capital energy-technology, Available Capital})/\text{BUILDING TIME CONVENTIONAL}$ ; Units: Euro/Year

investing in alternative energy=min((1-inclination to invest  
conventional)\*lack of actual capital energy-technology, Available  
Capital)/BUILDING TIME ALTERNATIVE; Units: Euro/Year

lack of actual capital energy-technology=max(0, desired capital energy-  
technology-(effective capital conventional+effective capital alternative));  
Units: Euro

Pollution= INTEG (production of pollution-absorption of pollution, INI P);  
Units: pollUnit

production of pollution=Capital Conventional Energy-Technology\*COEFFICIENT  
CAP-POL; Units: pollUnit/Year

sunk cost conventional=Capital Conventional Energy-Technology; Units: Euro

sunk cost alternative=Capital Alternative Energy-Technology; Units: Euro