# Ex Ante and Ex Post Sustainability of Energy Choices

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**Abstract:** The challenge of sustainability has reached everybody. The concept is mostly used as a normative concept but has too many interpretations. "Ex ante" sustainability will be ensured by the modeling procedure and the proper setting of time-scale and impact range. "Ex post" sustainability, as the judgment of "next generations", can be reached only if the model includes the changing preferences of future observers. The modeling philosophy of system dynamics provides a reasonable method to avoid the intragenerational and intergenerational subjectivity of this term. The problem of ex ante and ex post sustainability will be demonstrated with a model of the energy system in a "small world". The decision-makers face the situation how to allocate the finite fossil energy reserve between energy efficiency retrofit of buildings and development of renewable energy potential. This is a realistic dilemma because they have to satisfy although the operating energy demand of the world and they do not know how much fossil energy is still available.

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## Introduction

The challenge of sustainability has reached everybody. It penetrates the researcher's communication and it is a popular phrase in the dictionary of politicians, bureaucrats and CEOs as well. The watchword is a sustainable world, a sustainable Europe, a sustainable life-style, a sustainable government, a sustainable business, a sustainable sustainability. We do not exactly know, what one means saying or hearing this term, because the interpretation varies from speaker to speaker, from profession to profession, from audience to audience.

Most of the advocates of the sustainability concept are linked somehow to biology or ecology or they raise fears for Nature tilting out of balance. There is an interesting contradiction in this idea: on the one hand Nature is huge and it seems to be more sustainable as human work and we have to copy it, on the other hand Nature is something what needs to be protected. This apparent contradiction can be easily resolved if we bear in mind that not the sustainability of Nature, but the part of Nature valued by most human is very fragile. Nobody cares about the survival of cockroaches or bacteria (except Lactobacillus Acidophilus in the breakfast yoghurt), which are very robust and would survive even a nuclear catastrophe. This attitude based on the image of the collapsing nature due to a declining and destructive human culture is strengthened by the sometimes very impatient advocates of sustainability. Although they know, but they do not want to realize that Nature has other time-horizons than we do. They would like to have the same conditions, the same flora and fauna, the same wonderful landscapes as it might have been in the past, in times long ago before the industrial revolution. They do not tolerate flooding or bushfire, the extinction or the periodic population decline of some favorite species if it can be connected to the modern civilization. That is the motif why sustainability research focuses mostly on linking the human system to the ecosystem and mapping the current and future impact of the human activity. The normative requirement of this approach is that the 'human component (in terms of society, economy, government etc.) must be such that these reinforce or promote the persistence of the structures and operation of the natural component (in terms of ecosystem trophic linkages, biodiversity, bio-geochemical cycles, etc.), and vice versa.' (De Leo- Levin 1997, Hajnal 2009).

The sustainability definition of the Brundtland commission (1987) extends the time-horizon of human actions involving not only our life-time but the life-time of subsequent future generations: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The vagueness of this definition allows but does not require that the time horizon of human thought, more precisely the time horizon of human planning should overlap the time-horizon of the affected natural systems.

The sustainability concept has to be protected of becoming insignificant due to the vague use of the word without clarifying the meaning. As Patten (1997) remarked: "It is easy to understand as a general concept, for example: a sustainable system is a renewable system, living or nonliving that survives or persists for an indefinite, or specified, noninfinite time." Even if we share this general approach, we have a lot of problems developing practical decision procedures based on a set of regulations in favor of sustainability.

The goal of this paper is to contribute to the precision. We will attempt to explore sustainability as systems characteristics and look at the concept from the viewpoint of the system designer. In the narrow focus of the paper is the problem of ex ante and ex post sustainability. The problem of designing and evaluating sustainable systems will be demonstrated by a small comprehensive model about basic energy choices inducing the transition into the post-fossil epoch.

## Intragenerational sustainability

Sustainability is a time-dependent concept. The chosen time-horizon by the Brundtland commission of "future generations" will be weakened by most advocates to the next generation. The duty of our generation is to preserve the natural capital in order to ensure the well-being of our – grandchildren. The next logical step in shortening the time-scale is to examine the possibility of creating sustainable systems for our generations. This step does not make superfluous the time-dependency of the concept, but requires the involvement of new ethical, social and economical dimensions as allocation of goods, equity, communities, social discounting, etc.

Reviewing the efforts to make sustainability assessment we must realize that not only the proper setting of the time-horizon seems in most cases unrealizable, but although the practical implementation of sustainability is very difficult. The practice of governments and local authorities shows an explicit insensitivity to the problems of time, setting absolutely no time-scale in sustainability issues (Bond-Saunders 2011).

The allocation of natural and human-made capital, the access to sustainable (or any) technology is so limited for the majority of mankind that the problem of intragenerational sustainability cannot be resolved without creating a 'sustainable present for all'. Sustainable system design includes not only the dimension of time but although the dimension of place. This provides the possibility and burden focusing sustainability to locality i.e. to all spaces, all spots on Earth affected by the system.

## Intergenerational sustainability

The necessity of intragenerational sustainability does not supersede the burden of extending the time-horizon to the subsequent generations. This will lead to an interesting situation. The designer and the judge of the system is not only a different person, but comes from different generations, different times with diverse knowledge, ethics, values. We have to distinguish between the sustainability statement made by the designer of the system and of the judgment made by the future observers . This leads to the concept of ex ante and ex post sustainability. According to Derrisen et al. (2011): "Ex ante" sustainability is a hope of the system-designer to meet the criteria of durability and resilience, but it can be said only with a certain probability, that the system will not fail "ex post" the normative sustainability concept". The authors use of the term 'ex post' ambiguous. It can mean the result of the simulation, where the system-designer challenges his work, but it can mean the real procedures in a real world, where the implementation of the model will be judged by members of the next generation. We will explicate this second interpretation of ex post assessment, where the time-line of the evaluation will be adjusted to the reasonable systemic time-horizon and we have to postulate more future observers fitting the characteristics of the current system.

## Designing sustainable systems via models

### *Qualitative approach of modeling sustainability*

The system design via models reveals a simple way to sustainability planning. The model of the system is sustainable in a specific period if we run a simulation and the chosen variables are in the preferred range. If the results do not fit the chosen preferences we start an iterative process modifying the model and running simulations in order to get the required results. Theoretically we can modify the system structure as long as we get to an acceptable solution. If the model is good enough and can be validated, than the real system can be evaluated with the same set of indicators. The tolerated range of deviations due to measuring will be set as well. This approach suggests that sustainable system design had no specific methodology. The person of the designer, his or she's goals and preferences and the particular system structure, i.e. the qualitative dimension will ensure sustainability. Setting the proper time-scale is very important even in the case of this qualitative approach. We often experience equilibrium in non-sustainable system models if we look at some shorter periods and do not run the simulation for longer periods. The burden of extending the time-scale and the examining the impacts will lead to special steps that has to be considered in each sustainability planning method, so the qualitative approach is a necessary but not sufficient precondition.

### *Sustainability as modeling method*

The absolute sustainability of a given system would mean that the ex ante and ex post evaluation is the same. This is in fact only in the model world possible; this is the rationale of modeling per se. If we would like to design a sustainable system, we choose our preferences, we run the simulations and we look at the results. There is a precondition of getting the same judgment ex ante and ex post. We should have the same system, the same observer, and the same criteria. Not even in the case of models are always fulfilled these preconditions. Modeling requires time, effort and a lot of resources. The changing basic conditions and the abrupt changing of the real world may modify the system framework or rearrange the preferences of the assessment.

### *Ex ante sustainability of models*

Every system design starts with clarifying the system goals. Sustainability must be set as prime objective. Besides the previously mentioned qualitative approach to sustainability planning there are some methodological considerations that can be seen as normative steps in order to ensure the ex ante sustainability judgment:

1. We have to extend the time-scale till it fits the long-term impact of the system.

2. We have to look at the local and global impacts of the system during the whole time-scale in order to set the system boundaries.

3. We have to take into consideration the proliferation of the system and widen the impact assessment to this case.

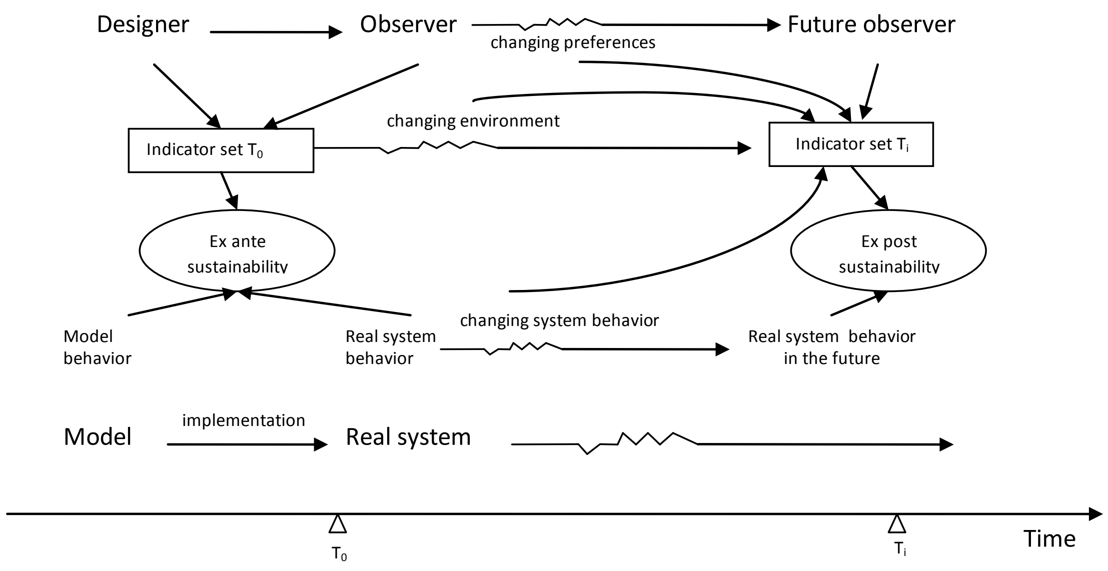
4. To ensure the long run of a system we have to embed it into the ecological, technological, cultural and social environment and/or we have to include the linking variables connecting the system to other subsystems and/or other dimensions.

These normative methodological steps can be derived from the burden of setting the proper time-set and ensuring the longevity of the system.

### *Ex post sustainability*

The realization of ex post sustainability seems to be easy, if we limit the time-scale and do not want to touch the intergenerational time-horizon. This means designing the model, implementing it and running the real system under the same or forecasted conditions. Ex post sustainability is dependent on the possible and/or inevitable changes of the environment of the running system and of the observer's preferences. Extending the time-horizon according to the intergenerational sustainability paradigm will lead to a very uncertain situation, as shown in Figure 1.

**Figure 1 The intergenerational sustainability assessment**




The difference between the ex ante and ex post assessment is the result of change. The change may come from the changing environment outside the boundaries of the system. There is a possibility that the model which seemed to be sustainable ex ante did not include such variables that turn to be essential for a long time. The answer to this problem is a design aiming resilience of the system. Resilience means that the main variables describing the system behavior will rebound to the preferred range after a shock due to external or internal procedures (Derissen et al. 2011). Good modeling skills and including all possible dimensions that could have impact on the system helps to intensify resilience.

The weighting of the possible destructive impacts and the degree of resilience depends on subjective estimating of risks and on the available information and resources during the modeling procedure. These problems are not unique to sustainability planning, there are well developed methods such as sensitivity analysis, risk estimation, scenario methodology both for technological and for ecological, economical system planning (Miller-Page 2007).

The most special problem of ex-post sustainability assessment in the real world in connection with real long running systems is the person of the observer and his position on the time-line. In very short times or in the case of simple systems it is plausible that person and/or preferences of the observers are the same, so he or she will evaluate the result of a system-implementation on the basis of the initial elaborated indicator set. In the long run not only the person of the observer will change, but he or she comes from another generation with new sets of preferences, new goals and stakes, new interpretations of sustainability. This will alter the basis of the evaluation, the indicators and the procedure as well, so the consistency of the assessment will be hurt. That is why foresight must gain a profound importance in sustainability planning.

## The role of foresight in sustainability design

The time scale of foresight has to delink from the subjective interpretation of the Brundtland definition. Namely it is not clear, which next generation should have to be considered and how many years is one generation 'worth'. With increasing life-time of the generations we have to expand the time window for the subsequent generations, the next generation will be in the position of observer and evaluator 40 years from now, the 2. generation 90-100 years from now and so on – the expanding is arbitrary, because we would have to make some estimations about the future trends of applying older or younger professionals (or citizens) having the skills, motivation and information to judge (and possibly redesign) the sustainability of the systems.

There is a more proper method to forecast the proper time-scale if we tear ourselves away from counting the time-horizon of next generations and try to estimate the system time-life inclusive all impacts made by the system. This does not make unnecessary that we mark the time of possible future observers on the time-line, because every system needs adjustments. Those users making important modifications are the observers as well. Extending the time-scale according to systemic requirements defines how many observers and how many assessment periods are to be considered in the system design. The common objection against extended time-scale that we do not have enough information and proper data to make this step creates the most serious practical and theoretical hurdle for sustainability design. The history and results of world models shows that this hurdle can be skipped by choosing a proper modeling philosophy.

The basic problem of the ex ante sustainability is the changing observer. In order to reach ex post sustainability we have to forecast the assessment principles and methods of the next observers. How is this possible without possessing omniscience? More specific: How is possible to define the changing values, preferences, manifested in the indicator set of future observer? The method of scenario analysis developed by strategic management is a practical solution to this problem. We make some estimation about the future and we examine the system behavior in these scenarios (e.g. Kleindorfer at al. 1993). This is not an answer to our problem this is only shifting he problem to another level, to the level of scenario-making, where the system will be prepared to more shocks and the system resilience will be enhanced, but the problem of imperfect and qualitative uncertain data persists.

The most comprehensive solution to maintain the consistency of the sustainability assessment would be modeling the possible changes in the future indicator set, i.e. modeling the preferences of the future observer. In order to master this challenge we have to go back to the normative methodological step of linking our system to the social system and to special dimensions of the social system as culture, ethics, business, demography, psychology, etc.

## The role of system dynamics in sustainability planning

Fulfilling the task of sustainable system design seems to be impossible, because it involves huge amounts of data, arbitrary extrapolations of present or past trends into the future and an increased, unmanageable complexity. The difficulty of this enterprise has far-reaching consequences: ignorance, simplification, and filtering. The various modeling techniques used in uncountable socioeconomic and socio-ecological studies amplify this effect. Stressing one dimension of sustainability and ignoring another is based sometimes on the difficulty of integrating qualitative variables from the social dimension into numerical models. Simplification and filtering is responsible for the misperception of profound connections. During the modeling procedure we have to simplify and we cannot take into consideration every flaps of a butterfly in Brazil if we would like to forecast a tornado in Texas. The burden of choice mobilizes our attitudes and values. Our incompatibility of revealing the most important correlations of sustainable systems has not only methodological, but although cultural and sometimes psychological cause. We develop a model in order to explore what would be sustainable, but we take into consideration only the "convenient" variables and dimensions of a given system.

The philosophy of system dynamics, stressing the causal relationships within the system and indicating that we have to find the key driving forces in order to forecast the future behavior may be the real solution to the ex ante-ex post sustainability assessment problem. The gap between the two approaches – modeling via correlations and via causal relationships explained earlier by Legasto and Maciariello (1980) is only apparently unbridgeable. If we rely on correlations, we hope that these are the superficial manifestations of cause and effect. If we look after the driving forces and the causes of system behavior, we cannot ignore the correlations of the data but we have to make one more step. We have to identify the key variables, the links and feedbacks (the deep structure) in the system which causes the correlations on the surface.

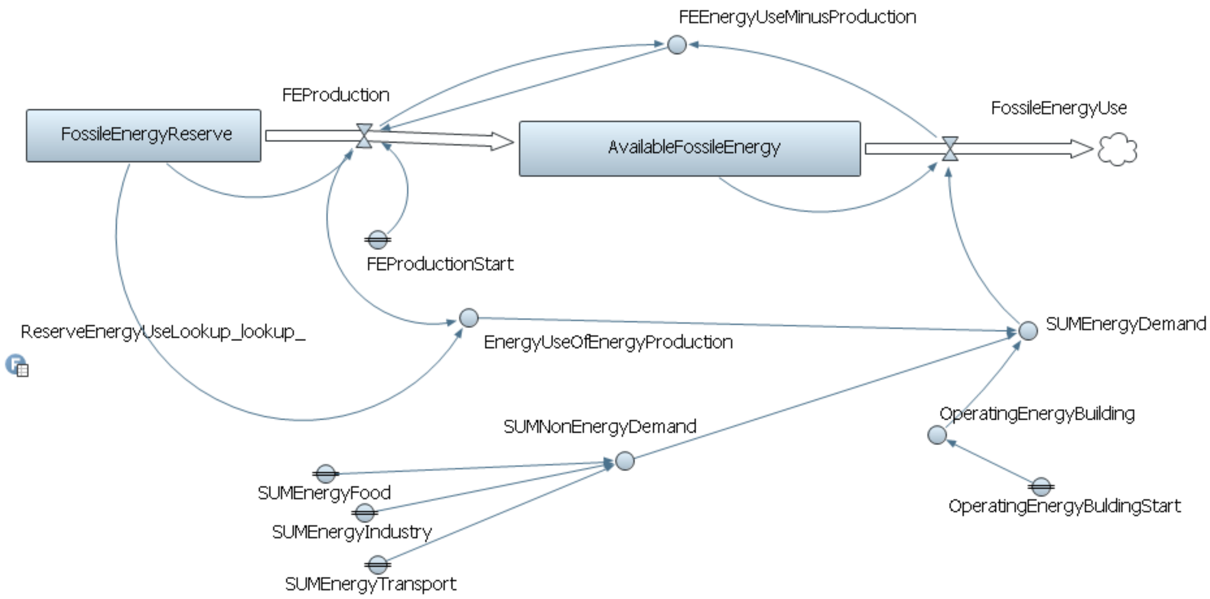
The approach via cause and effect simplifies the problem of the future observer. There are two possibilities. On the one hand we may try to find the possible causes of changes leading to the future indicator set and we try to design a system, which bears the probe of assessment with the new set of subsequent observers. The consequence of the first variation affects the modeling phase of sustainability design; this is the broadening and the adjusting of our initial expectations with the future expectations. On the other hand there is a theoretical possibility to expand the impact of the designed model to the future observer – and to try to fix the acceptance of the initial sustainability concept for the whole time-scale. The second variation may involve such politics and measures, which are outside of the current system boundary. Fixing the present paradigm of sustainability needs influence or education of whole professions or whole societies and the success depends on the speed of societal and environmental changes. Abrupt or chaotic changes stir up the force of tradition and eliminate the traces of our effort.

## Energy choices in a small world

Small models are often more impressive than huge simulations with hundreds of variables. The impact of ex ante and ex post evaluation and the importance of subjective preferences will be shown with a tiny and super-simplified model of energy system decisions in a hypothetical “small world”. The parameters of this model are not arbitrary; they mirror the data of Hungary, of a small Central-European country (ESY 2005) and are consistent with average energy demand for building retrofit and renewable energy investment. Only one parameter is entirely hypothetical, the amount of the total fossil energy reserves.

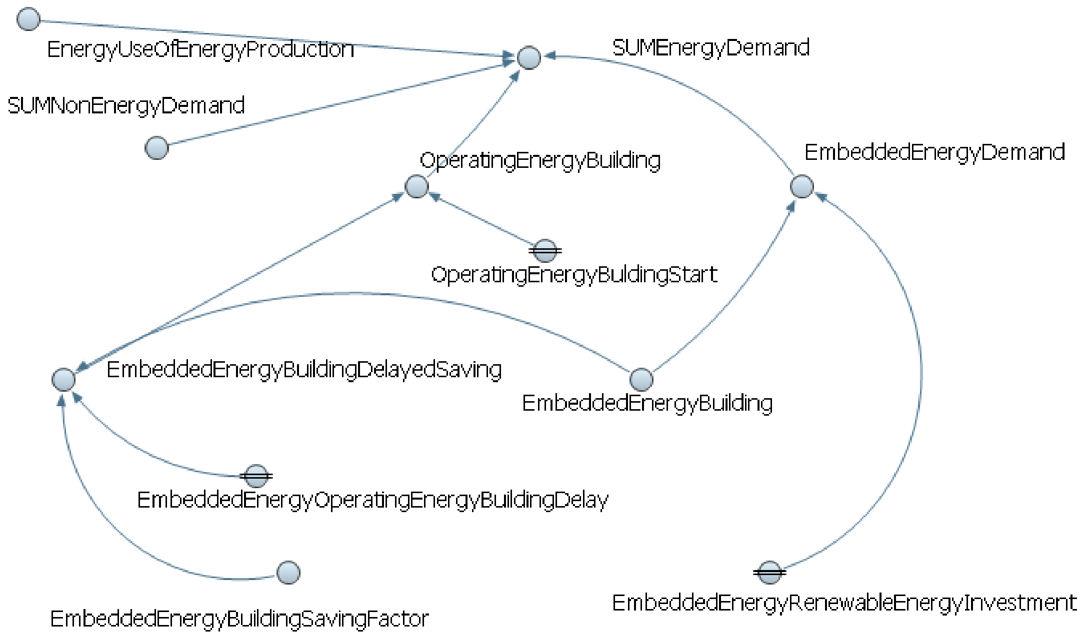
The zero point on the timeline symbolizes the moment when the decision makers realize that the fossil reserves of their world are limited, although he or she does not know the exact amount of this limited energy reserve. This is situation is similar to our present dilemmas, although we hope that in spite of the decreasing oil occurrence portrayed in the the peak oil theory we will able to switch to other fossil energy forms as coal or gas or shale gas. The objective external observer of this world knows that there is no possibility to discover new fossil sources, the last such reserve has approximately 1500 units energy, but it is likely that 200 units cannot be extracted. The yearly energy demand is 11 units, 6.9 units will be used for transportation, food- and industrial production. In this simulation we do not calculate with the volatility of this demand, it is fixed. The energy demand for ‘energetic purposes’ includes the energy used to gain the fossil energy and the operating energy of buildings (heating, cooling, etc.). The energy production will be harmonized with the fossil energy use which is equal to the energy demand. If the conditions of energy extraction do not change with time, the available fossil energy is able to cover the demand 139 years. It is more likely, that the energy demand of fossil energy production will increase as the reserve is running out, so this will be our basic scenario: the system will last in this case 99 years long. Figure 3 shows the initial situation of the energy system.

**Figure 2 The energy system of the small world at the beginning**




The decision maker realizing the future scarcity of the fossil energy starts a program in order to decrease the operating energy use of the building. This is a relative high amount of 3 units because our world has a temperate climate with cold winters and hot summers. The parole is that "the best energy is what we do not use", so they initiate a retrofit program for the dwellings and institutions. This includes such measures as insulation, shadowing, change of heating systems. They expect that in the long run this program will decrease the fossil energy consumption. This part of the model is shown on Figure 4. The retrofit will cost a lot of embedded energy, but this embedded energy will lower the operating energy in the long run. The effect takes some time, the delay is 3 years which represent not only the retrofit of the building, but the production of the insulating and other building material and the production of machinery.

**Figure 3 Operating energy and embedded energy of buildings**



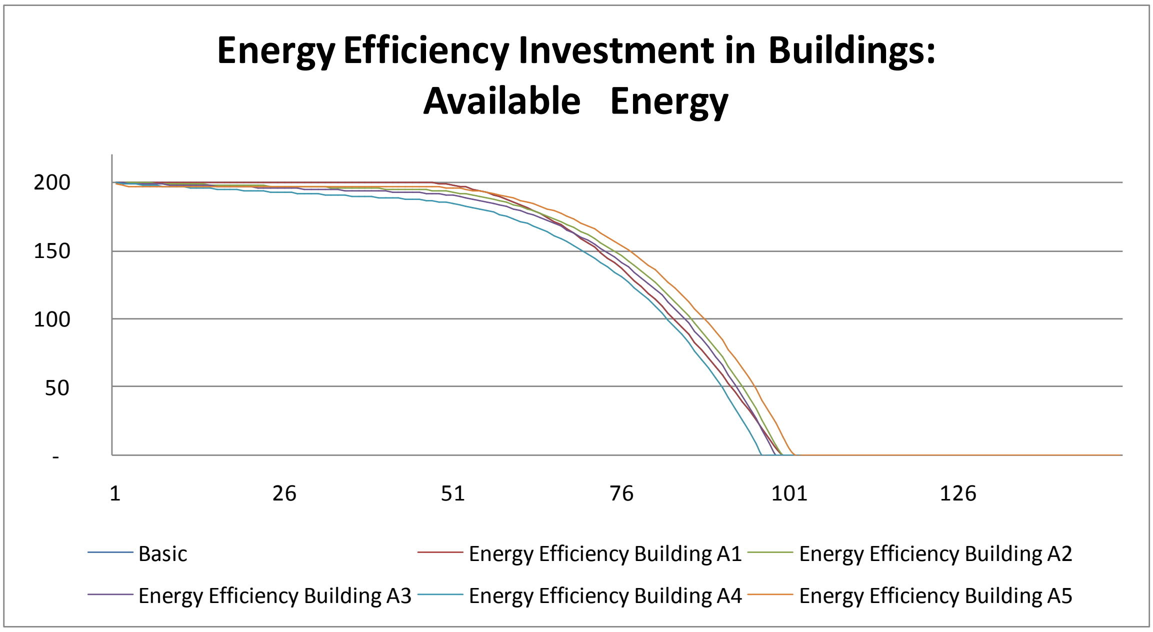

The main parameter variations of the 4 simulations involve the embedded energy and the saving factor per unit of invested energy.

**Table 1 Building energy retrofit scenarios**

| | Basic | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|---|
| Embedded energy | 0 | 0.3 | 0.6 | 0.6 | 1 | 2 |
| Saving factor by invested unit | 0 | 0.25 | 0.25 | 0.5 | 0.5 | 1 |
| Time of system collapse | 99 | 99 | 97 | 99 | 91 | 101 |

The system is not sensitive to this parameter. As shown on Figure 5 the saving per invested energy unit is not as important that it could postpone the time of collapse, even when the efficiency of this measure is very high and the society is likely to invest a third of the operating energy into the buildings. (We have to remark that the payback time of building retrofit depends on the used materials. The most used insulation materials as polystyrene are energy-intensive and not very durable, a life-time of 20-25 years is characteristic. We do not reconsider this in the simulation, so the simulation shows an optimistic demonstration of building retrofit.)

**Figure 4 The building energy retrofit scenarios**




This situation shows the failure of ex ante sustainability in system design only for the outsider observer knowing the total amount of the fossil energy. The designer of the system does not know how long lasts the fossil energy, so he may try to implement this politics. The motif to this decision can be characterized with the following presuppositions:

1. Renewable energy has a low density, so it is reasonable first to decrease the energy use of the buildings and increase the energy efficiency and after this should we invest in renewable energy capacity.

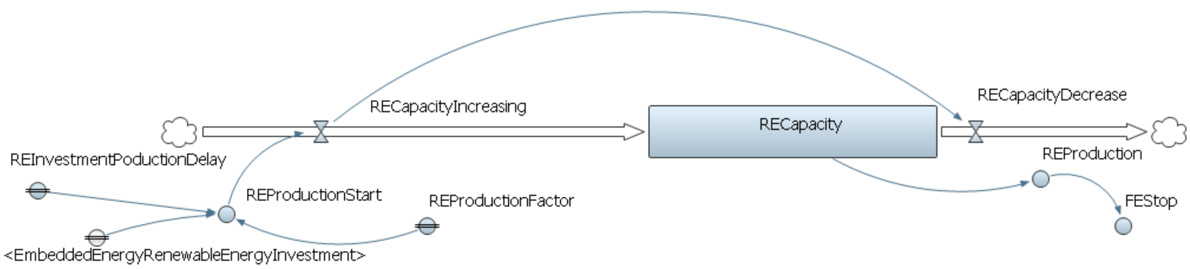
2. Although we know that the fossil energy reserve is finite, we have time, this will be the problem of the following generation. We have enough fossil energy, because we are able to satisfy our energy demand.

The structure of the energy system in the small world is very effective; it is such that the demand will be always satisfied till the collapse. The current observer/user will realize only in the last period “ex post”, when he has to switch to the reserve, that the system was unsustainable.

The observer in the future takes the results of energy efficiency for granted and will consider another factor. He or she will evaluate the energy system designed by his ancestors on the basis of the possible switch to renewable energy capacity. There is one factor indicating that the fossil energy is near to the end: the required energy of fossil energy production. This energy is increasing so our future observer will realize that without any hesitation he has to develop the renewable energy capacity.  As the inhabitants of our small world invested their resources mostly in insulation and building retrofit,  the renewable technology is  new for them and only few pilot applications are present, so we can postulate that their judgment about the scenarios A1-A5. They will judge it as non-sustainable and they will condemn their ancestor for the situation not having developed proper energy systems.  In order to save the intergenerational sustainability we have to take into consideration their preference having strong renewable energy technology.

There is another way to solve the future energy shortage, that is the investment in new renewable energy production without the spending the resources to building retrofit. Figure 6 shows this part of the model.

**Figure 5 Renewable energy production**



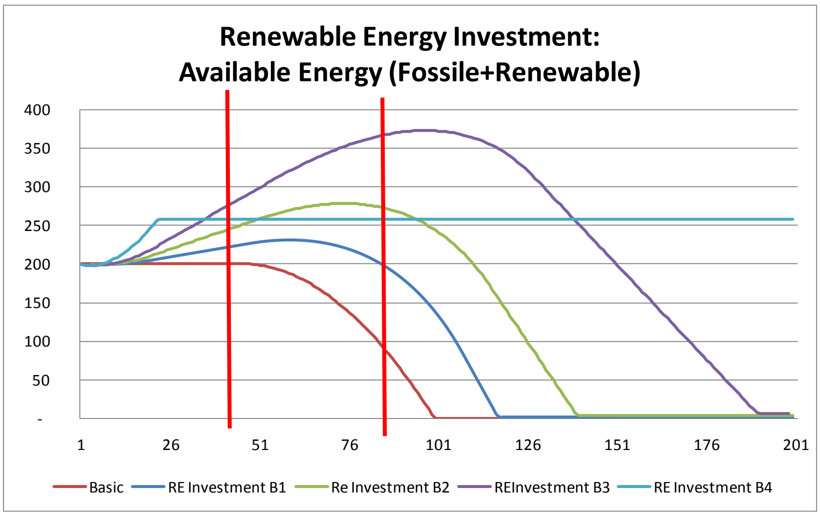

The establishing of  renewable energy capacity costs embedded energy and takes time (3 years), and it needs replacing in 20 years.  The table 2 includes the parameter variations of the renewable energy simulations.

**Table 2 Embedded energy in the case of renewable energy capacity investment**

| | Basic | B1 | B2 | B3 | B4 |
|---|---|---|---|---|---|
| Embedded energy | 0 | 0.3 | 0.6 | 1 | 1 |
| Renewable energy production factor | 0 | 0.3 | 0.3 | 0.3 | 0.6 |
| Time of system collapse | 99 | 117 | 138 | 189 | none |

That means for the decision-makers that there is a way to ensure the sustainability of the small world. As seen on Figure 7 this sustainability can be reached very fast (in a period of 22 years) in this simulation, if they are able to find the proper technology with production factor 0.6 and they are ready to spend every year 1 unit energy to this purpose. (This means that every invested energy unit in renewable energy capacity will result a capacity with efficiency 0.6.) In this last scenario we are able to stop the fossil energy production and reach an equilibrium satisfying the energy demand exclusively with renewable energy production.

**Figure 6 The renewable energy investment scenarios**




If we mix the two strategies that will shorten the time (from 22 to 18 years in the absurd case that the building's operating energy is zero) till the equilibrium is reached in the sustainable scenario but do not prevent the collapse in all other cases. That means that the mixed scenario starting with energy retrofit is only in the cases sustainable ex post, if we exactly know how much fossil energy is altogether available, we know, what time is necessary to develop the effective renewable energy system and we are able to fulfill this task before our fossil reserve runs out. In case of information uncertainty of our designer inside of the small world, the mixed strategy is as risky as the strategy of building retrofit and energy efficiency without any renewable energy investment.

The main task of the designer is to find the proper renewable energy technology. This will take time, there will be a lot of failures, he or she will have to experiment with technology, grid structure, logistics, and he will have to educate the people to raise awareness in connection with energy and energy production. If she chooses this way and develops a proper model she will be able to explore, that she has to reach a minimum renewable energy production factor of 0.6 and has to invest 1 unit per energy per annum - that is 5% of the whole fossile use of the small world. This result is very important because it shows the only way to reach an ex post sustainability of the energy system transition.

**Results of the simulations**

The decision-maker is always ex ante, the observer with the burden of evaluation always ex post. There is an interesting point in this simulation. Every society has limited resources. As we see theoretically it is possible to find a sustainable solution. The current sequence of decisions in the small world will be influenced by the time-preference of the decision-makers. Most of us has a time-horizon of 40-50 years, because we can imagine our life in 40 years (in the case, we are young enough), or the life of our children or grandchildren. The problem of long-term system design in society is that we hope, our descendants will find better solutions. In this view every scenario is a good solution, because in 40 years there will be enough energy to cover the demand. The ex post evaluation does not give the same result. If we set our hypothetical observer 40 years later, his judgment will be very different. He has the possibility to redesign the whole system, because he has enough fossil energy reserve to do this. The observer 40 years later, 80 years from now will find himself in a very different situation. Our decisions will determine his destiny. If he is on the false trajectory, than - without a correcting action 40 years before - the path of the future is predetermined and there is a high possibility of collapse. The intergenerational justice would require building up a new energy system to ensure the energy supply of future generations. Narrow time-horizon and the hope, that the descendants will find better solutions as he or she, prevents the decision-maker from fast acting.

In this very simple example we assume that the future generation will have the same technical knowledge and skills as we, so they will be able to run multiple energy systems. We assume, that energy supply will play as important role in the future as in the present, and the energy demand will be the same. These assumptions are such boundaries which have to be removed if we would like to foresight the future energy demand and the future energy production and conversion methods of a more complex world. But in this case we have to discover such interesting domains as population growth, technology proliferation, innovation dynamics and the future preferences of the inhabitants.

## References


Bond, A.J., Morrison-Saunders A. 2011. Re-evaluating Sustainability Assessment: Aligning the vision and the practice. In: Environmental Impact Assessment Review 31 (2011) 1–7

Brundtland Commission 1987: Our common future. Oxford University Press

De Leo GA, Levin S.1997:The multifaceted aspects of ecosystem integrity. Conservation Ecology [online] 1997;1(1):3. URL: http://www.consecol.org/vol1/iss1/art3

Derissen S. Quaas M.f., Baumgärtner S., 2011: The relationship between resilience and sustainability of ecological-economic systems. In: Ecological Economics 70 (2011) 1121–1128

ESY 2005: Energy Statistical Yearbook 2005. http://www.eh.gov.hu/gcpdocs/201201/energiagazdalkodasi_statisztikai_evkonyv_2005_ev.pdf

Hajnal, K. 2009: Knowledge Distribution in Paradigm Shift, The capital of intelligence - the intelligence of capital (ed.: Kiss F.), Infota, Budapest, pp. 41-64

Kleindorfer, P., Kunreuther, H., and Schoemaker, P. J. H., 1993 *Decision Sciences: An Integrative Perspective*, Cambridge University Press,

Legasto A. A., & Maciariello J., 1980, System Dynamics: A Critical Review, Studies in the Management Science, Vol.14, pp.23-43.

Miller, J.H. and Page, S.E. 2007: Complex Adaptive Sytems. An Introduction to Computational Models of Social Life. Princeton University Press.

Patten, B.C. 1998: Ecology's AWFUL theorem: sustaining sustainability. Ecological Modeling 108 (1998) 97–105