Heart Meets Mind: Smart Transition Management to Smarten Energy Systems in a Deeply Uncertain World

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Abstract

Enormous future investments are needed to replace old energy systems/technologies, and prepare them for future needs. Moreover, smarter technologies/systems are needed. And in this ever more complex, interconnected, and uncertain world, smarter policymaking in the energy field is certainly needed too. After all, current energy policymaking still mainly ignores dynamic complexity under deep uncertainty. This paper illustrates two model-based approaches for supporting policymaking for complex and uncertain issues as well as their combination. First, Exploratory System Dynamics Modeling and Analysis allows exploring and analyzing millions of plausible uncertain dynamic system behaviors and testing the robustness of policies. This approach is illustrated by means of a System Dynamics simulation model related to energy grid investments. Second, Experiential Model-Based Gaming allows policymakers to experience dynamic complexity and deep uncertainty, and helps them feel the need to embrace both in policymaking. Before having experienced different plausible futures, almost all high-level managers and highly-educated students that played such experiential games applied inappropriate strategies in most plausible futures played, and hence failed in the face of uncertainty. Failing repeatedly actually prepared them for thinking outside their old/reactive/predictive modes in subsequent bounce-casting sessions. Exploratory System Dynamics Modeling and Analysis and Experiential Model-Based Gaming may also be mutually beneficial: most subjects only acknowledge the need to take uncertainty and dynamic complexity seriously into account after having participated in experience-oriented gaming sessions.

Keywords: ESDMA, Experiential Gaming, Energy Distribution Network Operator, Asset Management

1 Introduction

Many great challenges –such as meeting current and future energy needs– are characterized by (dynamic) complexity, deep uncertainty, multiple dimensions, multiple actors, etc. Two of these characteristics are focused on in this paper: (dynamic) complexity and deep uncertainty. Two human inadequacies seem to make policymaking/decisionmaking in case of issues characterized both by (dynamic) complexity and deep uncertainty particularly difficult: the human mental capabilities and the human emotional receptivity. This paper proposes two tools to support humans with these inadequacies.

It is difficult –not to say impossible– to make appropriate policies/decisions for issues that are particularly characterized by both (dynamic) complexity and deep uncertainty without model-based support. But traditional model-based support is mostly inappropriate for such issues since it almost never seriously considers dynamic complexity under deep uncertainty. Exploratory System Dynamics Modeling and Analysis (ESDMA) may be a useful new multi-method for doing precisely that for this type of issues, and hence, supporting our inadequate human mental capabilities. The constitutive method(ologie)s of ESDMA are introduced in subsection 2.1.

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Moreover policymakers/decisionmakers are mostly reluctant when it comes to making policies/decisions when facing deeply uncertain dynamic issues –even if/when scientists or advisors use appropriate methods and take dynamic complexity and deep uncertainty seriously into account. It seems as though they not only need to know that a particular policy/decision is appropriate but that they also need to *feel* the policy/decision is the appropriate one. Experiential Serious Gaming (ESG) may be a useful approach for doing precisely that for this type of issues, and hence, supporting our inadequate human emotional receptivity. ESG is introduced in subsection 2.2.

Both method(ologie)s are illustrated by means of an example from our work in (smartening) energy systems/technologies.

After having introduced both method(ologie)s in section 2, section 3 illustrates the use of ESDMA for policymaking related to energy systems/technologies. Section 4 illustrates the use of ESG for policymaking related to energy systems/technologies. Section 5 contains concluding remarks and future research.

2 Methodology

2.1 From Traditional System Dynamics to Exploratory System Dynamics Modeling and Analysis

2.1.1 Switching Modes: From Forecasting to Exploration

Conventional forecasting, planning, and analysis methods are not suited for dealing with dynamic complexity (Senge 1990) and even less so for dealing with deep uncertainty: prediction of dynamic behaviors and certainty about probabilities, validity, and optimality cannot be obtained for (future) multi-dimensional systems characterized by high degrees of dynamic complexity and deep uncertainty. Moreover, improving models by increasing the level of detail or their size does mostly not help much: after all, 'all models are wrong [but] some are just more useful' (Sterman 2002). It may even be harmful if there is little time to act or uncertainties cannot be reduced, since it is very time-consuming and may generate the illusion that all uncertainties can be and are reduced.

Instead of focusing on predictability, optimality, and attempting to develop ever more detailed models validated upon past conditions, it may be more useful to develop small fast-to-build models, *explore* different model formulations and a plethora of uncertainties, and test effectiveness and robustness of policies in the face of parameter uncertainties, function uncertainties, structure uncertainties, model uncertainties, and possibly other uncertainties.

2.1.2 (Exploratory) System Dynamics

Traditionally, System Dynamics (SD) is used for modeling and simulating dynamically complex issues and analyzing their resulting non-linear behaviors over time in order to develop and test the effectiveness of structural policies. Mainstream System Dynamicists have assumed for decades that uncertainties are omnipresent, and hence, that trajectories generated with SD simulation models should not be interpreted quantitatively as point or trajectory predictions, but that they should be interpreted qualitatively as 'modes of behavior'.

However –with today's computing power– SD models may also be built specifically for the purpose of exploring the potential influence of uncertainties on dynamically complex issues. Such Exploratory System Dynamics (ESD) models are preferably fast-to-build and easily-manageable models, and consequently, rather simple and highly aggregated. ESD is an interesting approach for exploring uncertainties, and testing the effectiveness of policies in the face of these uncertainties. However, ESD in isolation may be insufficiently broad and systematic to firmly base policymaking under deep uncertainty on.

But the combination of ESD with Exploratory Modeling and Analysis (EMA – a methodology for exploring deep uncertainty and testing policy robustness – see following paragraph) may be useful and sufficient for broadly and systematically exploring and analyzing plausible dynamics under deep uncertainty, and for testing the effectiveness and robustness of policies without neglecting deep uncertainty and dynamic complexity.

2.1.3 Exploratory Modeling and Analysis

EMA consists of using exploratory models (not necessarily SD models) for generating tens of thousands of scenarios (called an 'ensemble of future worlds') in order to analyze this ensemble of future worlds and to test the robustness of policy options across the ensemble. Using this method, it is therefore tested whether the outcomes are acceptable for all transient scenarios generated by sweeping the entire multi-dimensional uncertainty space. As such, it can be used to generate insights and understanding about the functioning of systems and the robustness of policies, by taking deep uncertainty seriously into account (Lempert, Popper, and Bankes 2003) (Agusdinata 2008). In EMA, the question is not when to *measure more* nor when to *model better*, but *how to explore and analyze* dynamically complex systems under deep uncertainty, and *which policies do effectively and robustly improve system behavior under deep uncertainty.* EMA consists more precisely of following stages:

(*i*) developing 'exploratory' –fast and relatively simple– models of the issue of interest,

(*ii*) generating an ensemble of future worlds (tens of thousands of scenarios) by sweeping uncertainty ranges and varying uncertain structures and boundaries,

(*iii*(a)) analyzing and clustering dynamic behaviors, identifying bifurcations, et cetera,

(*iii*(b)) and/or specifying a variety of policy options (preferably adaptive ones), and simulating, calculating, and comparing the performance of various options across the ensemble of future worlds.

Many data analysis techniques are available to investigate in step (*iii*(a)) the effect of underlying mechanisms/(inter)actions/conditions, to separate different modes of behavior, to determine the conditions that lead to these different modes of behaviors, to find bifurcation points and critical variables. But for policymakers/decisionmakers, it may be even more interesting to define different (adaptive) policies/strategies and test their (relative and absolute) robustness (effectiveness given all uncertainties considered – step (*iii*)(b)). The effectiveness/robustness of policies can then be evaluated over the entire multi-dimensional uncertainty space without having to analyze/understand millions of outcomes. In other words, the effectiveness/robustness of policies/strategies could be evaluated and compared without reducing uncertainties related to the system of interest, without having acquired full understanding, and without getting overwhelmed by combinatorial complexity.

2.1.4 Exploratory System Dynamics Modeling and Analysis

Since EMA requires handy models for generating (thousands of) plausible scenarios, and ESD requires methods for exploring deep uncertainty, they are actually natural complementary allies (Pruyt 2007a), and could be combined as Exploratory System Dynamics modeling and Analysis (ESDMA). Examples of ESDMA can be found in (Lempert, Popper, and Bankes 2003; Pruyt 2010; Pruyt and Hamarat 2010a; Pruyt and Hamarat 2010b; Pruyt, Kwakkel, Yucel, and Hamarat 2011; Kwakkel and Pruyt 2011; Pruyt and Kwakkel 2011; Pruyt, Logtens, and Gijsbers 2011) as well as (Kwakkel and Slinger 2011; Kwakkel and Yucel 2011).

2.2 Switching Modes: From Traditional Serious Gaming to Experiential Serious Gaming

2.2.1 Interactive Games and Flight Simulators

Interactive games (Duke 1974; Greenblatt and Duke 1975) are 'serious' games, in which real people (inter)act. They could be used for different purposes: they enable experiments in which human (inter)action processes can be observed in a (semi-)controlled environment, by means of which hypotheses could be tested, conclusions could be extended, models could be validated. Such games could also be used –apart from aforementioned traditional 'scientific uses'– for experience-based learning under deep uncertainty.

In all cases, real people assume the role of key stakeholders and (public) policy makers. Players have to make the kind of decisions that the corresponding real world actors have to make in reality, thus simulating human (inter)actions and strategic behaviors.

In *model-supported* interactive games, computer models are used to add real world complexity, perform detailed calculations, generate and display specific information, and deduct the overall system behavior resulting from actor (inter)actions. These models also keep track of decisions made by the players, and hence, could be used to compare the actual behavior of many players, also with 'optimized' and/or 'simulated' behavior. The computer models used in this research are (exploratory and experiential) System Dynamics simulation models.

System Dynamics model-supported (board) games are not new: well-known examples include the Beer Game, Fish Banks, and Strategem. However, these games always lead to the same outcomes (modes of behaviors), insights and conclusions. They are not focused on (deep) uncertainty – quite the opposite.

Flight simulators –also called learning environments or microworlds– are interactive decision-making computer games, based on computer models, that are mostly used to 'enable [users] to pre-experience the changed environment, preparing them better to face the transients of the change implementation and the challenges of managing the post-change situation' (Winch 1998, p354) (see also (Kim and Senge 1994; Groessler, Miller, and Winch 2004; Langley and Morecroft 2004)), iow, for learning purposes. However, they could also be used for experimental and validation purposes. In these flight simulators, players need to take decisions at certain moments during the model run, the consequences of which are then calculated by means of the model. Flight simulators are mostly built for a single player or team: the computer interactively generates the behavior of the other actors.

2.2.2 Uncertainty-focused Games and Flight Simulators

Although uncertainty, and asymmetric/partial/private information ought to be important ingredients in all interactive games and flight simulators, they are mostly ignored or reduced. Depending on the game, different uncertainties could be included: consumer or market uncertainties, resource uncertainties, technological uncertainties, competitive uncertainties, supplier uncertainty, policy uncertainties, etc. Players should also only receive *partial* information that would also be available to them in the real system. At most, bounded rationality should therefore be assumed. Players (inter)act based on partial information available to them, as well as upon their beliefs, motivations, perceptions of the situation, and perception of the level and location of the major uncertainties. These beliefs, motivations, and perceptions cannot be controlled, and only steered to a certain extent: specific situations could be created in these games, and beliefs, motivations, and perceptions could be asked for and monitored at every step.

2.2.3 Experiential Serious Games and Flight Simulators Related to Uncertainty in Energy Transitions

Experiential serious games are even less laboratory-like. These experiential sessions and games are designed specifically to allow the participants to experience the importance of uncertainty and of taking uncertainty into account in policymaking/decisionmaking.

3 Exploratory system dynamics modeling and analysis to smarten energy systems

3.1 ESDMAs to Smarten Energy Systems

Within our first line of research, different ESDMAs related to energy transitions have been –or are currently being– performed, for example ESDMAs related to:

1. the development of world wind power potentiality (Hamarat and Pruyt 2011)
2. the transition of the electricity generation sector – using a generic energy transition models, a huge EU-27 electricity generation transition model (Pruyt 2007b), an agent based electricity generation transition model (Yucel 2010; Kwakkel and Yucel 2011), and combining all three models (WIP)
3. the transition of the electricity distribution sector (see below)
4. the energy transition in the built environment (WIP)
5. the energy transition in automotive transport (WIP)
6. plausible influences of scarcity on energy transitions (WIP).

The ESDMA related to the transition of the electricity distribution sector is used below as an illustration.

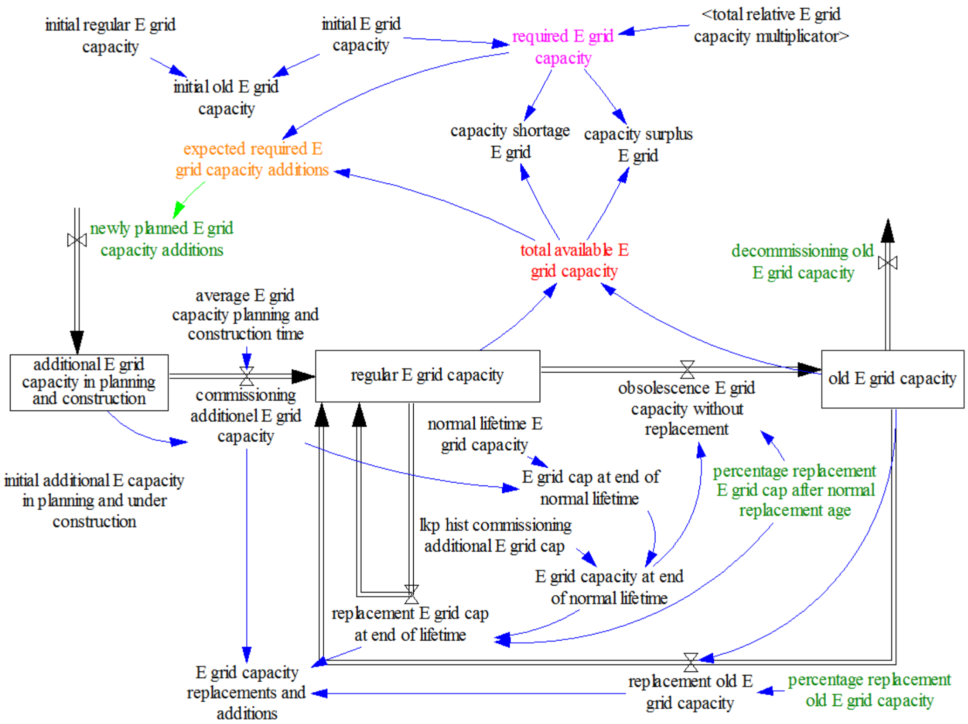
3.2 Illustration: ESDMA Related to Distribution Network Operation

3.2.1 Structure of the ESDMA Model

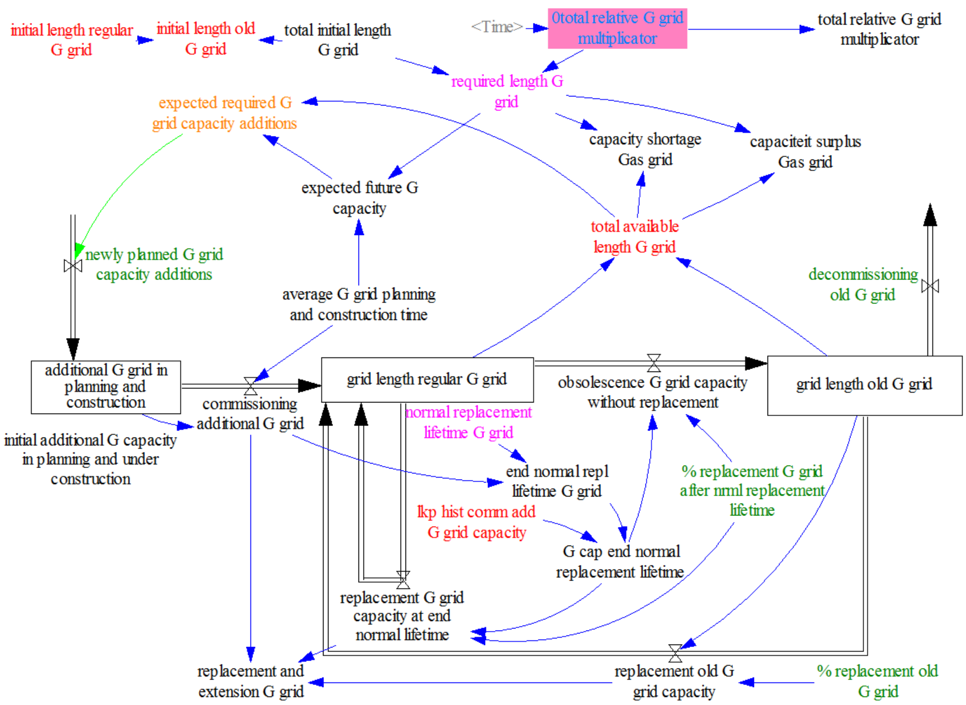
The model used here to illustrate ESDMA is an adapted version of the model developed specifically for an experiential game for an Electricity/Gas Distribution Network Operator (see section 4). The model consists of four submodels: an electricity grid capacity submodel (see Figure 1), a gas grid capacity submodel (similar to the electricity grid submodel), a rudimentary financial submodel, and a rather large scenario submodel. The first three submodels are endogenous, the scenario submodel is exogenously driven. The model is all about strategic asset management of –and hence decisionmaking related to investments in– electricity and/or gas distribution grids.

Eight different –exogenous but internally consistent– transient scenario sets (lookups with time series) were developed for the game (see section 4). To generate an ESDMA 'future', one of these eight transient scenario sets is called randomly (the red input variables in Figure 2(b) and Figure 2(a)). The scenario values at any time step are then transformed: however, the shape and size of these transformation functions is uncertain. Hence, three rather different versions are defined in the ESDMA for each of these transformational lookup functions: randomly selected versions of these lookup functions are then used to transform the values of the randomly selected transient scenarios into input values for the ESDMA (light blue variables in Figure 2(b) – non-existent in Figure 2(a)). Parameter uncertainty is dealt with too (orange parameters in Figure 2(b)). Hence, the ESDMA version of the model deals with scenario uncertainty (in red), function uncertainty (in light blue) and parameter uncertainty (in orange). Compare Figure 2(b) to Figure 2(a) in order to put the model-integrated adaptations for an ESDMA into perspective.

The ESDMA is performed from within a shell (written in Python) which generates the experimental design and controls the execution of each of the experiments. The shell delivers the inputs needed to generate a particular future to the SD software package (Vensim DSS), and packages and stores the data of the future world after it has been simulated by the SD software. The

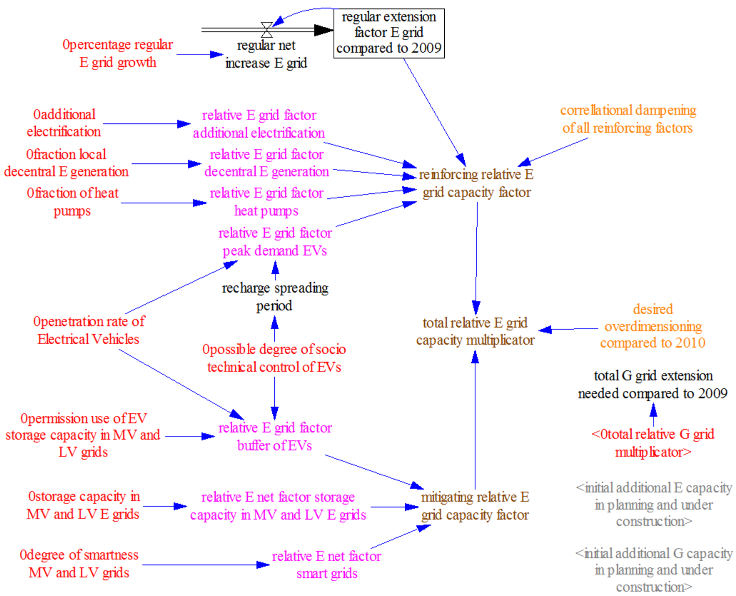


(a) simplified electricity distribution network

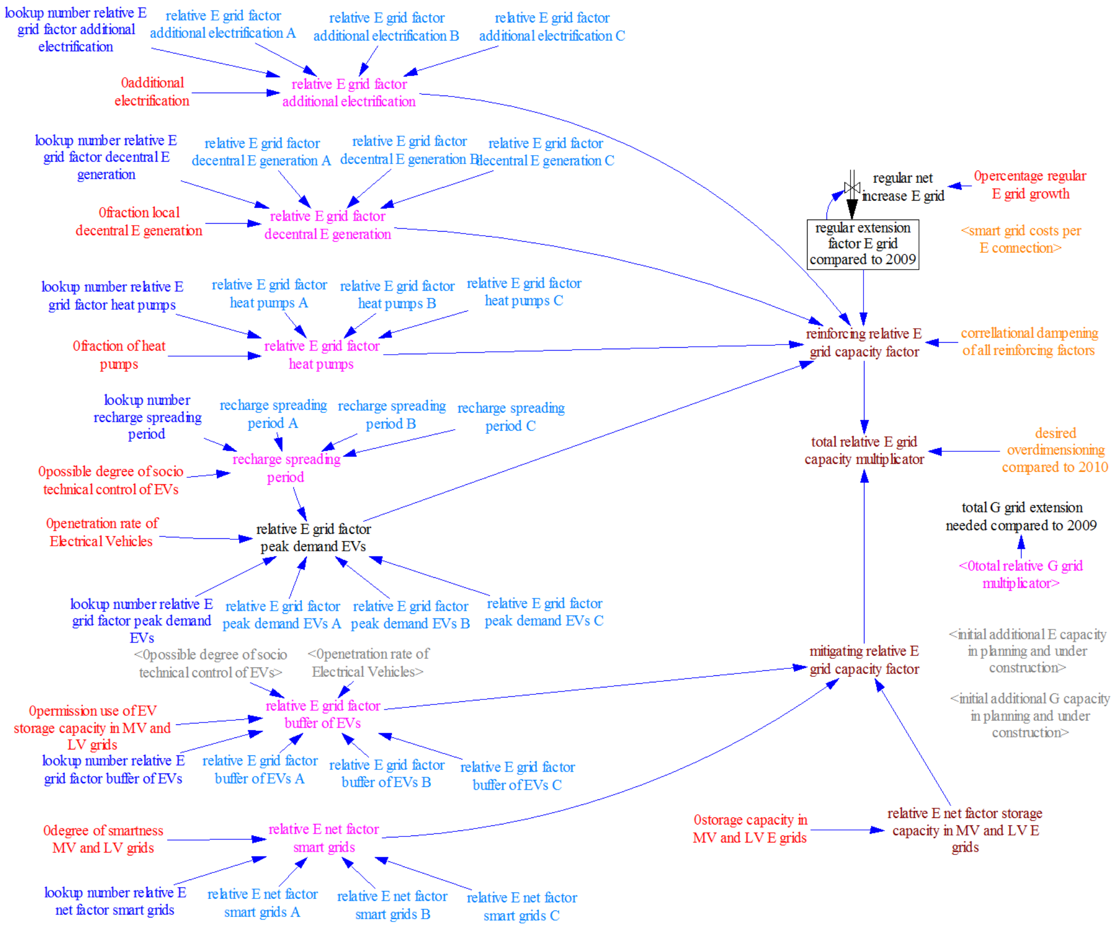


(b) simplified gas distribution network

Figure 1: Stock flow structures of the simplified electricity and gas distribution networks (2 out of 4 views)



(a) Stock flow structure of the scenario generator of the game/SD model



(b) Stock flow structure of the model-integrated part of the scenario generator of the ESDMA model

Figure 2: Stock flow structure of the model-integrated part of the scenario generator of the SD model versus the ESDMA model

analysis of the ensemble of future worlds and the visualizations (either to support the analysis or to support the communication of key findings) are performed on the ensemble of future worlds using Python scripts.

3.2.2 Analysis of ESDMA Behaviors

Figure 3 shows 2000 'futures' for two rather regressive/reactive investment strategy in terms of four key output indicators and two decision variables –from top to bottom– the capacity shortage of the electricity grid, the capacity surplus of the electricity grid, the electricity grid capacity replacement and extensions, the capacity shortage of the gas grid, the capacity surplus of the gas grid, the gas grid capacity replacement and extensions.

Figure 3 shows clearly distinct modes of behavior: they can be separated by means of time-series clustering and analyzed by means of (forest) classification and regression trees.

The visualization of all future worlds or the envelopes of the ensembles give a good idea about the range of behaviors but offer a biased story in terms of likelihood. The end state histograms displayed in Figure 3 show that most behaviors are found closer to the origin than suggested by the envelopes. However, the bottom-most graph and histogram suggest that overcapacity in the gas sector is very plausible.

3.2.3 Designing Robust Policies

The next EMA/ESDMA stage is to design –preferably adaptive– policies/strategies and to test their robustness – whether they perform well over the entire ensemble of future worlds. This analysis is not performed here because the model –having been developed for an experiential game– cannot be used for that purpose. Instead, it will be used in the following section (in its basic form) what it was developed for in the first place: experiential gaming.

4 Experiential serious gaming to smarten energy systems

4.1 Games to Smarten Energy Systems

Within our second line of research, many different experiential flight simulators and games related to energy systems transitions have been, are currently, or will soon be, developed. Following games and flights simulators related to the transition of the electricity sector are worth mentioning[1]:

1. *Technology Developers Investment Flight Simulators*: focused on the role of Technology Developers, and possible technological lock-ins.

2. *Electricity Generators Investment Flight Simulator*: focused on the role of electricity generators, and resulting generation mix at the system level.

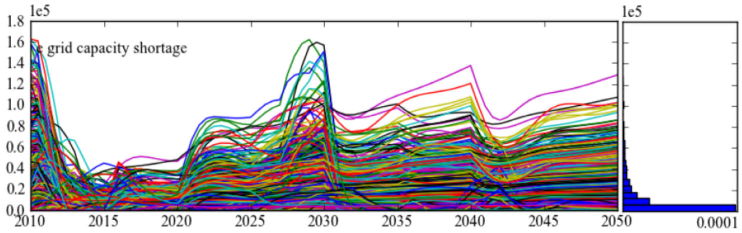
3. *Energy Infrastructure Investment Flight Simulators* for transmission/distribution companies.

4. Technology Developers & Electricity Generators *Energy Investment Games* (and Flight Simulators): combining the roles and (inter)actions of technology developers and electricity generators.

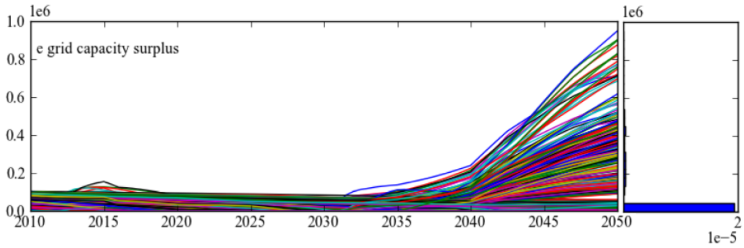
5. Technology Developers & Electricity Generators *Policy Design Games*: adding the role of policy maker to the previous game.

6. Comprehensive *Energy Investment Games* combining all roles in a Multi-Actor Systems game.

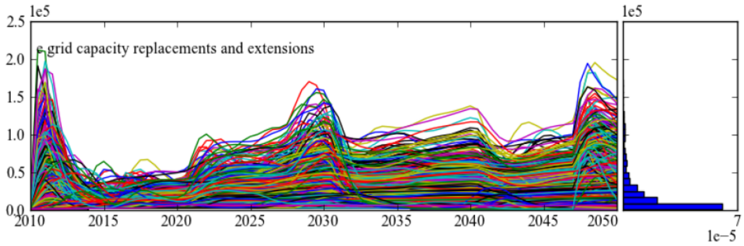
[1]A series of games and flight simulators related to the energy transition in/of the built environment is currently being developed in our lab too.



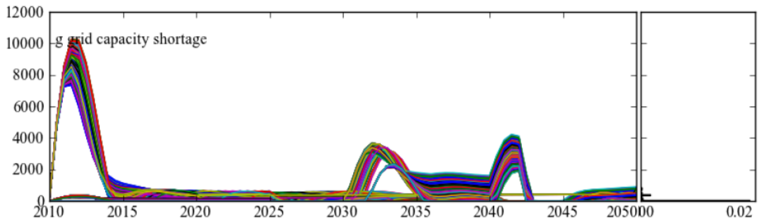
(a) capacity shortage of the electricity grid



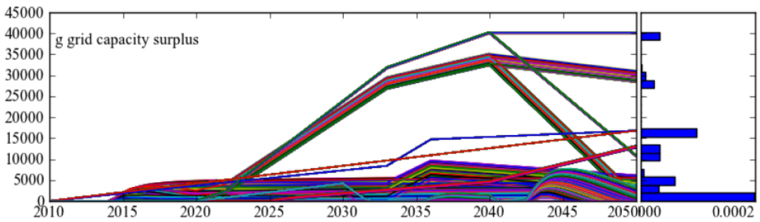
(b) capacity surplus of the electricity grid



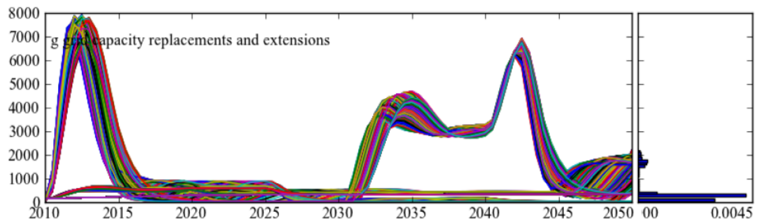
(c) gas grid capacity replacement and extensions



(d) capacity shortage of the gas grid



(e) capacity surplus of the gas grid



(f) gas grid capacity replacement and extensions

Figure 3: Results of a regressive strategy for 2000 futures for 4 key output indicators and 2 regressive decision variables

7. Other derived games such as *Oil/Energy Price Games* focussed on the reaction of different actors to changes in primary energy prices.

All these games / flight simulators deal with (parts of) the transition of the energy/electricity sector towards sustainability. Figure 4 displays a simplistic representation of the energy/electricity sector which helps to frame the different flight simulators and/or games.

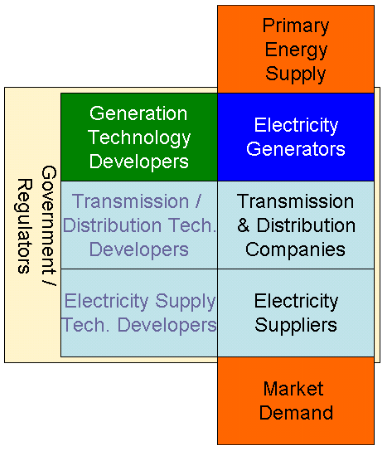


Figure 4: Simple representation of the electricity/energy market to frame some flight simulators / games

These games could be developed for different purposes: from experimental to experiential. The following subsection illustrates the experiential use of an *Energy Infrastructure Investment Flight Simulator* (see 3) above), more specifically for/from the point of view of Distribution Network Operators (DNOs).

4.2 Illustration: The DNO Flight Simulator

The DNO flight simulator was tailor-made for a Dutch electricity and gas DNO to pull managers out of their predictive modes and to help them broaden their perspectives on the uncertain(ty of the) future – they applied the same strategy for decades and most of them foresaw just one future[2]. The gaming session was followed by a short bounce-casting dialogue about deep uncertainty and the appropriateness of their current asset management strategy (replacing x % and expanding y% of their grids) under deep uncertainty.

First, participants –senior managers and asset managers of the DNO– were informed about the goal of the afternoon (to experience deep uncertainty about the future in order to rethink the DNO's current strategies in the face of deep uncertainty about the future) and about the event itself.

Before running a first 'trial scenario', basic information about the logic of the virtual world –a slightly simplified and geographically aggregated version of their world– they were about to play in was provided. In other words, the model structure (see Figure 1) was briefly presented before starting the actual gaming session. Key information provided related to their virtual electricity grid (initially 142000 km of which about 11000 km older than the maximum replacement lifetime of 37 years) and their virtual gas grid (initially 42000 km of which about 21000 km older than the maximum replacement lifetime of 80 years), both with an average planning/construction time of 1 year.

Participants were familiarized with the interface (see Figure 5), their decision variables (planning of electricity and gas network capacity replacements, planning of new electricity and gas

[2]Interestingly, electricity grid managers seem to believe in an all-electric future and gas grid managers seem to believe in new and smart gas grids partly replacing the electricity grid.

network capacity extensions, decommissioning of old electricity and gas network capacity, and investments in smart(ness of) grids), and had some time to play around in order to get familiar with the dynamic implications of their virtual decisions.

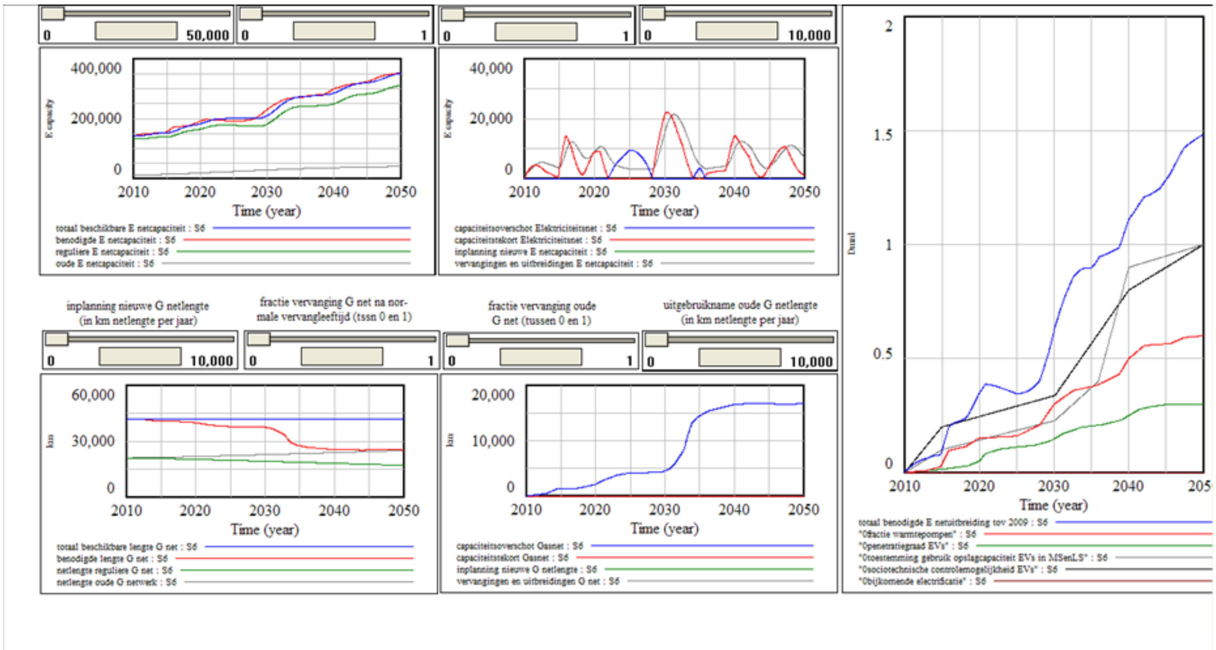


Figure 5: Simple interface of the DNO game: decision variables, company dashboard (four views on the left) and external dashboard (environmental scanning of important indicators related to the business context) – displaying here the results of model-based decisions for scenario S6

After warming-up, groups of three participants were asked to develop an investment strategy (simultaneously for their gas and electricity grids) and to apply this strategy using the model-based flight simulator without foreknowledge about the future (scenario). Relevant and available pieces of information about past and present were provided through the interface. After playing the game given a particular scenario, the teams were asked to revise (if desirable) their strategy and to play the same scenario (hence with foresight) with their new strategy. After this first iteration, the teams were asked to apply their revised strategy again, but now with new scenario settings, in other words, once more, but in a new uncertain future world. After playing without foresight, teams were asked to adapt their strategy and play it again under foresight. And so on, and so on.

Apart from warming-up with the S0 scenario, participants played following seven scenarios:

- Scenario S1 is a rather boring scenario –merely an extension of past developments– which requires grid replacements and extensions in line with the past replacements and extensions (even their 'old strategy' is appropriate for this scenario);
- Scenario S2 is a scenario in line with the 'official future scenario' of the Dutch government, without any shocks, in which DNOs are allowed some control over decentralized electricity generation;
- Scenario S3 is the same as S2 but with local electricity storage (e.g. in electrical vehicles);
- Scenario S4 is radically different: it requires smaller investments in the electricity grid and much bigger investments in the gas grid;
- Scenario S5 requires high investments in the electricity grid –without low voltage use of electrical vehicles and smart grids– and low investments in the gas grid;

- Scenario S6 (see Figure 5) corresponds to a slightly cyclic version of scenario S2;
- Scenario S7 is characterized by cyclical growth of the electricity demand and a decline of the gas demand followed by development in the opposite direction.

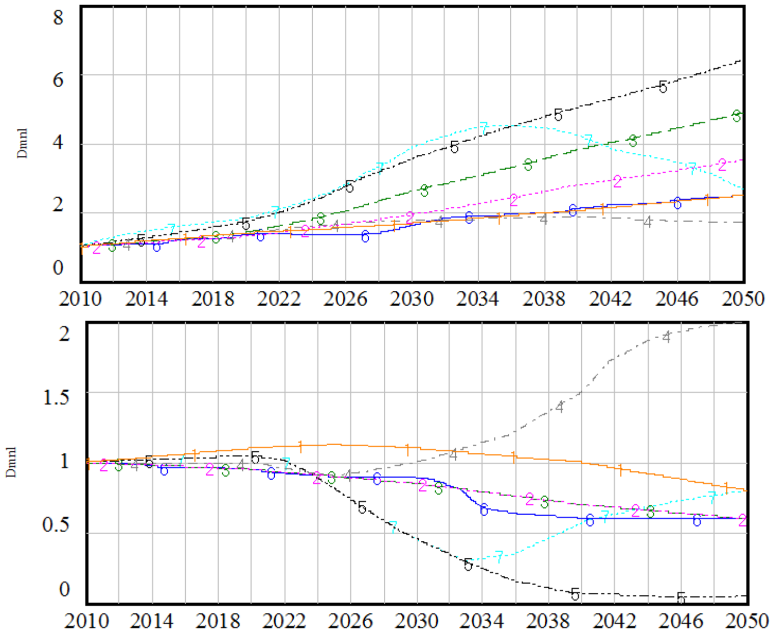


Figure 6: The resulting total relative electricity grid multiplication factor (top) and the total relative gas grid multiplication factor (bottom)

Ten scenario variables that may seriously influence grid development drive the *total relative electricity grid multiplication factor* and the *total relative gas grid multiplication factor* (see Figure 6).

Figure 7 shows the results of the same reactive strategy applied to these 7 scenarios for 4 key output indicators –from top to bottom– the capacity shortage of the electricity grid, the capacity surplus of the electricity grid, the capacity shortage of the gas grid, and the capacity surplus of the gas grid. These scenarios are plausible and gradual –big shocks do not occur. And even these smooth and plausible scenarios caused serious problems to all groups. Although it is possible to outperform this reactive strategy, most players were not able to do so. Figure 8 shows for example the behavior of four variables (*electricity grid surplus* –1–, *electricity grid shortage* –2–, *new capacity planned* –3–, and *capacity replacements and capacity extensions* –4–) for a simplistic regressive strategy (top), for three typical group strategies, and two atypical group strategies (bottom) for scenario S6.

All results were collected after playing through all scenarios. These results were grouped and analyzed during the break and were used during the debriefing and a subsequent bounce-casting dialogue.

4.3 Conclusion: Games for Experiencing Uncertainty

Uncertainties dealt with in this workshop were far from ‘deep’ – they were moderate uncertainties at best. This particular experiential gaming session was nevertheless an eye-opener for most participants of the workshop. Gaming through different futures increased their impressionability. Participants experienced and afterwards acknowledged the importance of uncertainty and agreed that further research related to distribution network asset management under deep uncertainty

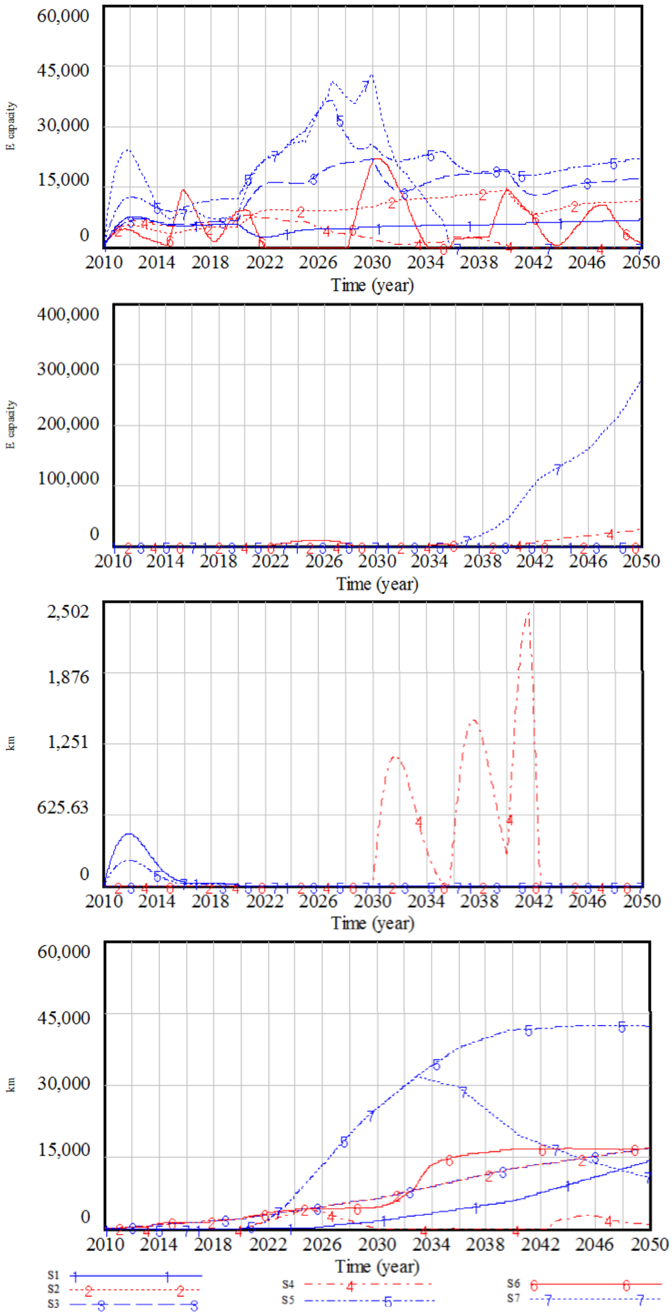


Figure 7: Results of a regressive strategy applied to 7 scenarios for 4 key output indicators –from top to bottom– the capacity shortage of the electricity grid, the capacity surplus of the electricity grid, the capacity shortage of the gas grid, and the capacity surplus of the gas grid.

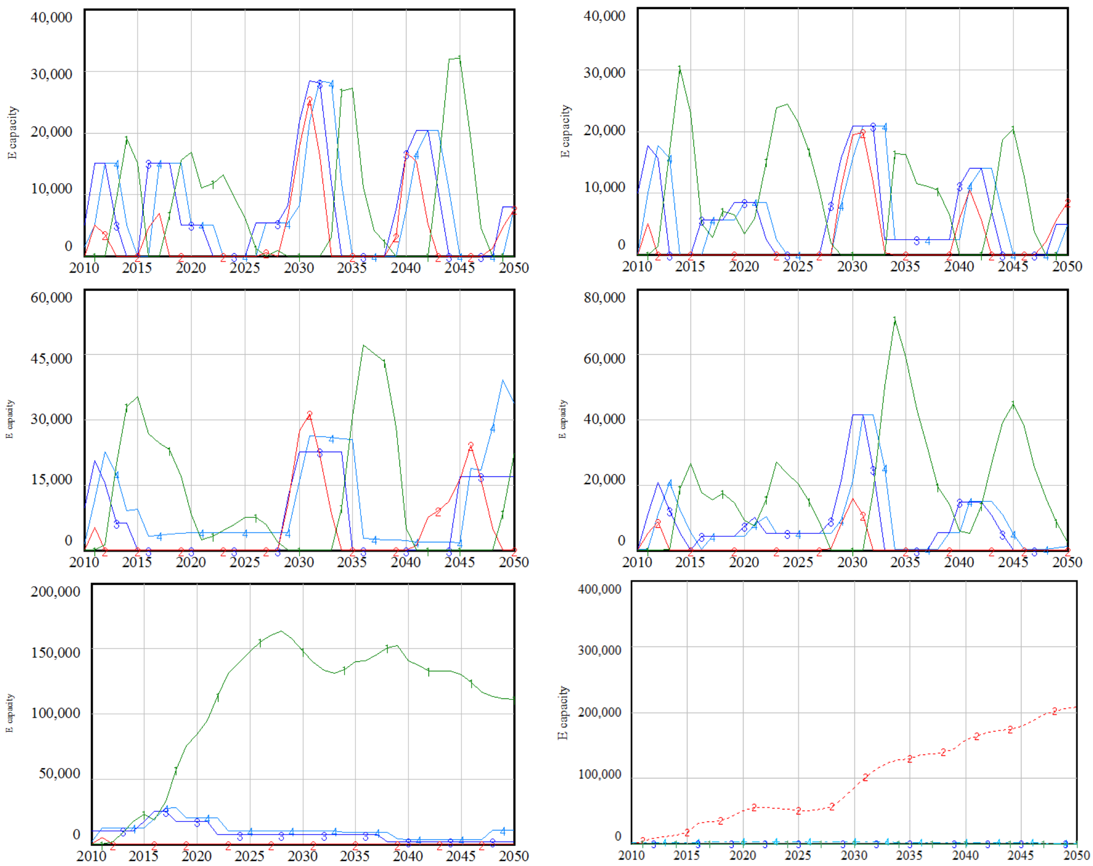


Figure 8: Simplistic regressive strategy (top) versus three typical groups and one atypical group (bottom) for scenario S6 for the following variables: electricity grid surplus –1–, electricity grid shortage –2–, new capacity planned –3–, capacity replacements and capacity extensions –4–

was necessary. Plausible futures were embraced and ideas about possible (adaptive) strategies were advanced.

The underlying model and the decision variables in the game were perceived by some lower-level network managers –making operational and geographically-specific replacement and expansion decisions on a daily basis as part of their job– as inappropriately aggregated: a possible geographic mismatch could indeed occur even if the strategy would be appropriate in aggregated terms. These remarks opened up the discussion about predictability of 'the' future and optimal strategies for one predicted future versus deep uncertainty and adaptive strategies that are robust for ensembles of plausible futures.

It could be said in general that this type of experiential games is very useful for opening up rusty minds for considering deep uncertainty. It allows enthusing policymakers/decisionmakers for 'ensemble forecasts' about the future (tens of thousands of plausible scenarios) and for considering and testing adaptive and robust instead of optimal policies.

5 Conclusions: Mind meets heart – Exploratory Modeling and Analysis & Experiential Gaming

Effective policymaking/decisionmaking requires at least the internal alignment of knowledge ('the mind') and beliefs ('the heart'). The human mind is inadequate for generating knowledge about deeply uncertain dynamically complex issues. And even if that knowledge would be available, then knowing alone would not be enough: Policymakers/decisionmakers also need to *feel* the need to take uncertainty seriously into account in policymaking/decisionmaking – they need to be convinced by the omnipresence of uncertainties and the importance of taking them into account.

Two approaches were discussed in this paper: one for supporting our inadequate mental capabilities (knowing) and one for supporting our inadequate emotional capabilities (feeling). These two approaches are complementary: ESG could help policymakers/decisionmakers to feel the relevance of taking deep uncertainty into account and ESDMA could help policymakers/decisionmakers to understand how they could take deep uncertainty into account. ESDMA could also be useful prior to experiential gaming for designing the game (e.g. deriving plausible scenarios). And experiential gaming could also be useful for ESDMA by providing insights into reactions/behavior or real policymakers/decisionmakers.

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