Speeding Up Energy Transitions: Gaming Towards Sustainability in The Dutch Built Environment

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Abstract. *The built environment accounts for the largest proportion (approximately 40%) of energy consumption in most countries and consumption levels are still rising. This significant proportion makes it an essential sector to address in the sustainable transitions agenda. In the Netherlands, it is generally accepted that the energy transition of the built environment with the current policies is much slower than required given the urgency of the foreseeable problems and the substantive system delays. Hence, there seems to be a need for experimentation with innovative policy instruments, governance mechanisms, and systemic conditions to fill in the gaps in understanding. In this context, this paper explores the possible use of games for understanding why there is so much inertia in the transition process. We use a three-step process to arrive at some conclusions; first, we begin by developing a conceptual model to illustrate the possible causes of the aforementioned slow transition as derived from the literature, and then, we proceed to discuss the potential roles of games for managing the transition in the built environment. Finally, we combine the prior two steps and illustrate with a System Dynamics Model-Based experimental game, developed predominantly for hypothesis-testing purposes. Based on the results of the game we conclude by exploring the possibilities for future research.*

Keywords. *Simulation Game, Energy transition, Built environment, Inertia, Learning effect, model-based gaming, hypothesis-testing.*

1 Introduction

1.1 Transition and Inertia

The Dutch energy system needs to become sustainable over the next 10 to 50 years in order to dramatically reduce its climate change impact and to be able to deal with foreseeable energy supply problems. However, energy systems and societies are examples of large-scale socio-technical systems (STS) that generally change slowly and gradually –typically with time horizons of 50 to 100 years– and not necessarily in the desired direction, even if many actors see the urgency of system changes. This phenomenon is also reflected in the current state of the Dutch energy transition. The ranges of possible sources of clean energy are plenty and concepts for a successful transition are available or are currently under development. In the residential sector alone, many technologies already exist that are proven, available and affordable. Yet, the adoption of these concepts are much slower than required given the urgency of the foreseeable problems and the substantive system delays. Hence the system is characterized by high inertia.

The literature on the causes of inertia is fragmented and dispersed. There seems to be gaps in knowledge and understanding that cannot be closed with traditional approaches. Although plausible causes of inertia have been recognised, it is still not fully understood what inherently holds back real energy system actors, how their individual actions cause inertia and slows down energy transitions towards sustainability, and what may actually speed up energy transitions. In view of this, we have developed an integrative conceptual framework, which combines the explanations giving in transition and urban sustainability literature (Itard &Meijer 2009; Beerepoot 2007; Van Bueren et al 2011; Van Hal, 2000; Rogers, 1995; 2003 etc.), on the possible key barriers to the diffusion of innovations in the built environment (see Figure 1). Distinguishing between different barriers to the diffusion of innovations is important for designing appropriate policies for coping with the inertia. In this research, we classified the barriers to the realisation of significant energy and emission saving potential into four main categories based on the major categories observed by the European Alliance of Companies for Energy Efficiency in Buildings (EuroACE): Market and information barriers, political and institutional barriers, technological barriers and behavioural barriers.

1.2 Barriers to the Diffusion of Innovations in the Built Environment

Economic and Information barriers. The Economic barriers refer to all those barriers that are financial or stem from the market environment such as the costs of energy, low access to capital by home owners and high initial costs of the energy efficient innovations (see Figure 1). The information barriers refer to those barriers that are inherent due to a lack of, or exchange of, information such as that associated with asymmetric information and knowledge on sustainable buildings (see Figure 1.).

Technological barriers. These forms of barriers refer to those that are specific to the energy efficient technology itself, for example, technological uncertainty in terms of costs and performance. In addition, the ease of process integration of the new technology and the lack of proven innovation effectiveness all serve as impediments to the adoption of those particular technologies.

Political and institutional barriers. Political barriers refer to those barriers relating to government and its conduct. Institutional barriers on the other hand, consists of formal, planned institutions such as (state) organizations and regulations, and, more informal evolved institutions characterized by ground rules: institutions act as interaction patterns that structure, but do not determine behavior, and they define the space within which actors act, select problems and solutions, and set priorities (Ostrom, 1990). Some examples of political barriers related to the diffusion of innovations include political uncertainty (uncertainty about governmental behaviour, regimes, and policies) and ambiguity in interpretation of current policy (see Fig.1). With regards to institutional barriers a typical example is related to the overall characteristics of the building sector – which generally comprises many small players and risk avoiding behaviour (Van Bueren et al 2011), resulting in a sector resistant to change, innovation and to government interventions (including voluntary policy instruments for the promotion of change).

Behavioural barriers. Behavioural barriers are sometimes referred to as *'social barriers'* because they are comprised of society's attitudes and beliefs which then act as barriers to action (Wilkinson & Reed , 2007). For example, one particular group of barriers revolves around a lack of knowledge or understanding of issues. An example is the rebound effect; this effect in this context refers to the situation where a measure aimed at reducing environmental impact induces a behavioural response (or any other systematic response) that actually offsets the intended effect of the measure in question (Van Bueren et al 2011). It just so happens that sometimes, interventions aimed to support sustainability have undesirable effects. Well-known examples of how technological innovation aimed to save energy backfired include the standby feature of home appliances. Instead of turning off the appliances, people leave the appliances running on stand-by mode (Van Bueren et al 2011), thus using more instead of less energy, our perspective is that user-convenience, in itself, may be problematic in this context.

1.3 Model – Based Gaming

The conceptual model (Figure 1) illustrates the key components of the physical and social characteristics of the Dutch built environment. Essentially, the model depicts the complexities (multiple dimensions and multiple actors involved at different life cycle phases of buildings) as well as the uncertainties (technological, market & political uncertainty) which acts as barriers to the diffusion of innovations in this environment. One of these barriers is focused on in this paper, namely the market and information barriers with regards to lack of understanding (information) of key actors and the tendency for potential adopters to look at up-front initial capital costs rather than project life costs (see Fig. 1). This paper makes use of a system dynamics model- based simulation game to test one of many hypotheses of this highly complex setting.

It is challenging to make appropriate policies/decisions for issues that are particularly characterised by complexity, uncertainty and multiple stakeholders without using some form of simulation model that allows for an illustration of the dynamics of the system of interest and allow for the assessment of the long term effects of specific interventions possibilities. However traditional quantitative models generally assume that decision makers are rational agents or make optimal decision routines, based on traditional economic assumptions. Model- based simulation games may provide a means to challenge these assertions as it provides an environment where the decisions of actors are directly imputed into the model.

Furthermore , decision makers and individuals in general tend to be mostly reluctant when it comes to making policies/decisions when facing deeply uncertain dynamic issues, such as climate change, adoption of unfamiliar energy innovations etc., despite the professional advice of experts or scientists. As noted by (Pruyt, 2011), there seems to be a need to go beyond knowing, but also feeling that a particular policy/decision is the appropriate one. Our opinion is that the complicated and anomalous explanations for inertia in energy transitions suggest that it would be futile to attempt to explain it

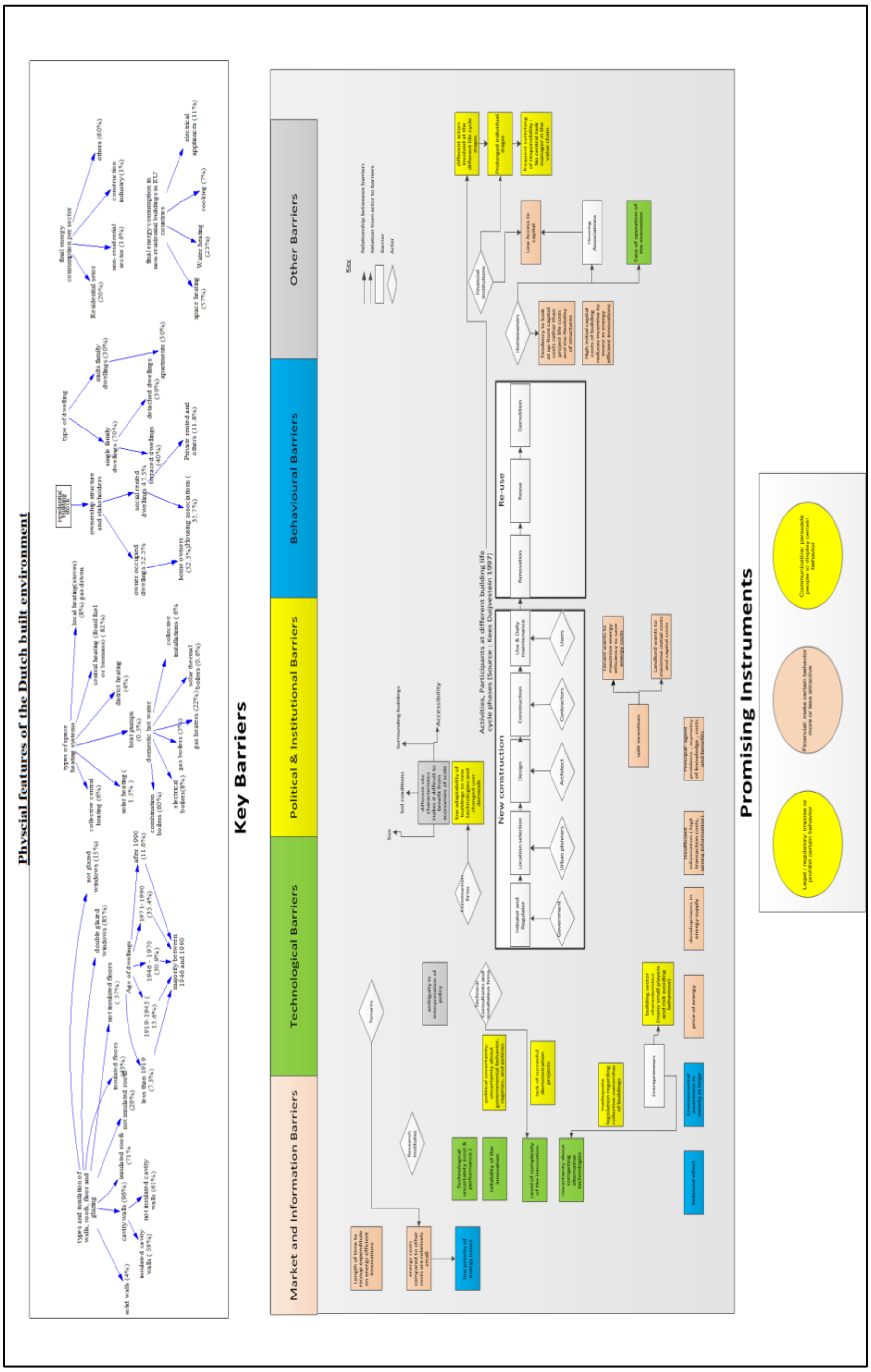


Figure 1: Conceptual framework, outlining the physical environment, key barriers and policy instruments in the diffusion of innovations in the built environment

solely through economic rational actor models and implementing economically rational policies.

The added value of simulation games in this context can be derived in multiple ways: (1) it may allow for real experimentation with policy instruments, governance mechanisms, and systemic conditions (e.g. competition between innovative technologies, interaction between different actors, deep uncertainties and lack of information etc.) before real-world policy implementation, hence, assisting policy makers in responsible decision making (2) improvement and validation of decision making agents and decision routines in quantitative transition models, and (3) accelerated experiential learning by real system actors. In light of these possibilities, we aim to develop and use several model-based system games, ranging from simple flight simulators to multi-actor systems games for multiple purposes, in order to understand what the causes of inertia and what policies could be used to speed up the transitions in the built environment.

In this paper we explore how we can use simulation games in an experimental fashion to test for some hypothesis, as derived from our conceptual model with a focus on the market barriers to the diffusion of innovations in the built environment. Our case study focuses on energy used to supply domestic hot water and evaluates the extent to which market and information barriers, such as a lack of understanding of basic dynamic systems, as represented by learning curves of domestic energy technologies (Micro – CHP and high efficiency boilers) in the residential sector as well as the extent to which the h initial costs of these technologies have an impact on decision-making.

Section 2 introduces the methodology, system dynamics (SD) model – supported interactive game and illustrates the use of the model-based game (MBG) for testing hypothesis related to inertia in transitions in the built environment. In section 4 we present the results of the game and discuss possible reasons for the performance of the participants. As our results did not find many significant performance differences, the conclusions section (5) focuses on future interests of our research.

2 Methodology

2.1 Introduction

There are several purposes for which games can be designed for, through a review of simulation game literature (Bots & Van Daalen 2007; Maier & Grobler, 2000; Uithol et al 2001; Duke & Geurts, 2004; Meadows et al, 1993; Sterman, 1989) we have derived some of the common uses/ types of simulation games:

1. Experimental games
2. Learning Games
3. Training Games
4. Validation Games
5. Evaluation Games
6. Fun Games
7. Experiential Games

This types of games listed above are by no means exhaustive, however, they point to some interesting uses of games that may be useful for facilitating decision making. In this study, we make use of model based experimental game to test for hypothesis related to the lack of understanding of learning effects. Experimental games may be a useful approach as its benefits are twofold, first, by providing a much needed safe setting for participants to experiment and second, the possibility for analysts to make use of the results of the game for testing relevant hypotheses.

2.2 Illustration/ Case: Learning Curves in Dynamic Systems

The challenges faced with decision making under complexity in dynamic systems have been researched by a number of authors (e.g., Brehmer, 1992; Funke , 1991; Jensen, 2005; Moxnes, 1998; 2004; Rouwette et al 2004; Sterman, 1989a; Sterman, 1989b). Learning curves, one of these complex dynamics, have been identified in a range of industries (Dutton and Thomas 1984); their strategic implications have also been extensively explored. Learning curve research indicates that as cumulative production increases, unit costs decreases due to cumulative firm experience (Dutton and Thomas 1984). In simple terms, it expresses the relationship between production experience over time and unit costs of a good or service. These resulting learning effects have an effect in dynamic systems, where their impact is associated with delays, nonlinearities and feedbacks. Such systems are usually quite complex, and research has shown poor decision making in these settings. A number of articles (Rogers 1995; Beerepoot 2007; Itard &Meijer 2008; Van Bueren et al 2011) have emphasized the negative impact of high costs on the market diffusion of novel and efficient energy technologies , however few have explored the possibility of a lack of understanding of these dynamics as a key barrier to the market diffusion/adoption of energy innovations.

Here we address this knowledge gap by making use of the system dynamics (SD) model – supported interactive game, called the 'Learning Effect Sim'. We randomly selected two domestic heating boilers in the residential sector (Micro-CHP and High Efficiency boilers). , which provide substantial energy savings and are at different phases of the market diffusion and technological life cycle phases of development; thereby making it easier to distinguish between the learning curves of both technologies.

Hypotheses. The main purpose of this experimental game was three fold: (1) To test whether there will be a difference in responses between learners who received both textual and graphical information about learning effects on the interface as compared to those who received only textual information (2) test whether highly educated people faced with graphical dynamic effects, can successfully interpret these graphs (3) test whether people show better performance after having made a model about the learning curve (specific modelling experience).

2.3 Method and Materials

The experiment made use of an online, web based system dynamics simulation (constructed on http://www.forio.com). 131 participants from the Bachelor of Science courses of the Faculty of Technology Policy and Management of Delft University of Technology took part in the experiment. The students were divided into two groups, the treatment group and the control group

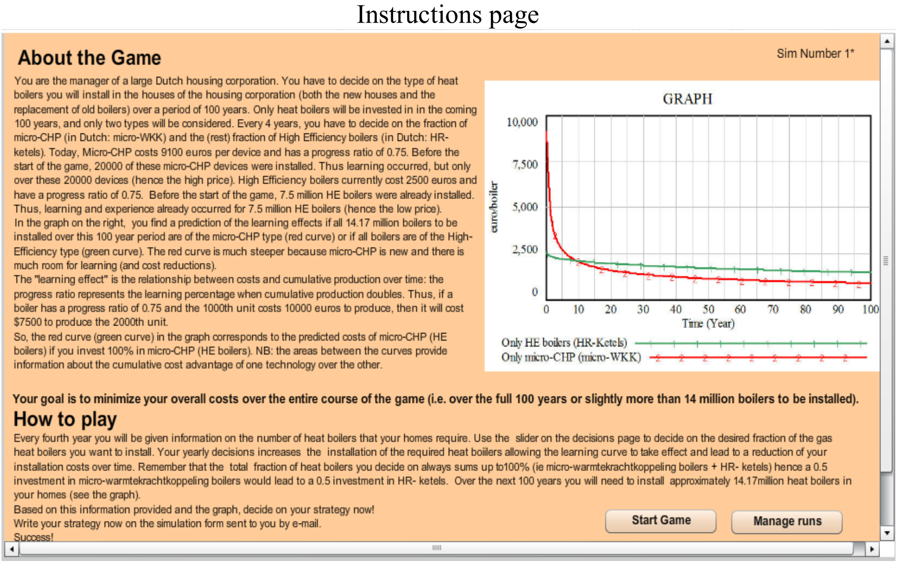
Experimental Design. The whole experiment was conducted in three versions. In the first version of the interface, the research participants were assigned randomly to one of two experimental conditions (one with graphical and textual inputs) and the other without the graphical input. After reading this information players proceeded to the actual simulation page where they could actually adjust sliders for the main input variable of the model (desired fraction of gas boilers), based on the required amount of boilers to be installed and see the effects in the form of graphs on the sales price/unit cost of both boilers (gas (high efficiency) boilers and solar (micro-CHP) boilers.

As performance in the first version of the game was so poor, we proceeded to improve the information provided in our interface as well as the underlying model itself which led to the creation of version 2 of the game (see Figure 2).

Version 2. In the second version of the learning effect simulation, there were a number of changes made to the previous version mainly with respect to information provided on the interface: 1) We used different domestic boilers, Micro-CHP and the High efficiency boilers 2) Version 2 provided information that learning and experience had already occurred on the previous boilers installed 3) In version 2 there was an explanation of the steepness of the learning curves. Micro-CHP boilers was said to have a steeper curve because it was newer and hence there was much more room for learning and hence cost reducing (this gave some suggestion into which investment would have higher net gains.) 4) In this version it was explicitly explained that the area between the curves provided information about the cumulative cost advantage of Micro- CHP boilers over high efficiency boilers , a quick look at the graph would have shown that there was more cost advantage in the Micro-CHP boiler over the high efficiency boiler. Though results here were still disappointing they were slightly better than version 1.

Multiple Choice Examination Question. In order to test for learning outcomes and ensure that participants were obliged to make the best decisions as they possibly could, we made use of an objective multiple-choice examination question at the end of the course (refer to appendix A). Those multiple choice questions tested understanding of the model (e.g. the main cause-effect relationships), provided perfect information on learning effects, provided full control over learning effects (no global effects) and specified that there was no discounting required. This ensured that players could make the best decision possible without worrying other factors coming into play.

Instructions page



Decisions Page

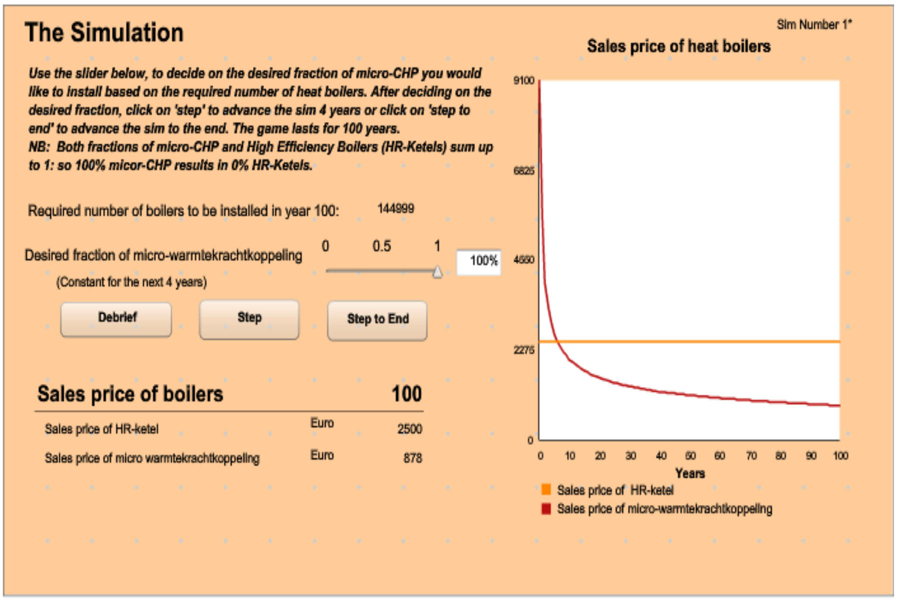


Figure 2. Interface of the Learning Effect Simulation (Version 2, Treatment1)

The Benchmark. An optimal solution is intuitively simple given that we have provided players with the definition and effects of learning over time on the unit costs of the two technologies; additionally, we provided them with graphical evidence of the learning effects of both innovations over time. The graph shows that though one technology (in version 1 solar boilers, in version 2 Micro- CHP boilers) have a higher initial value than the other (in version 1 , gas heat boilers, in version 2 high efficiency boilers) an increase in its cumulative installation over time reduces its unit costs to values below that of gas heat boilers. More importantly the area between the two graph curves reveal that there is more cost advantage in investing in solar(Micro-CHP) boilers than gas (high efficiency) boilers.

2.4 Procedures

The participants themselves were introduced to the interface during the lecture and encouraged to participate in the simulation. Participants could log in for the study and, based on their user names, were randomly directed to one of two web URLs, one of which pointed to test game (with graphical information) and the other to the control game (without information) of the program. Participants were only allowed to play the game once. Data was automatically stored to a secure web server. After two weeks, a debriefing of the results occurred via email.

3. Results & Discussion

3.1 Hypothesis 1

Our first hypothesis was the following: (1) to test whether there will be a difference in responses between learners who received both textual and graphical information about learning effects on the interface as compared to those who received only textual information. The statistical test revealed that there was no significant difference between the participants given the graphical information on the interface and those only giving textual information. Somewhat disappointedly, overall performance on the game with graphical information in both versions of the game, was only marginally better than the game without information (version 1: 12% better and version 2: 6 % better) (see Table 1. below). Because the tests were not significant, we cannot make any firm conclusions that participants performed better or worse across the game types however it is interesting to consider the possible reasons for the poor performance.

Table 1: Results from a cross tabulation concerning percentage-wise differences between control and treatment game

	Version 1 (% of correct answers)	**Version 2 (% of correct answers)**
Treatment group (with graphical information)	17% (rounded off to one decimal place)	27%(rounded off to one decimal place)
Control group (without information)	11%(rounded off to one decimal place)	15%(rounded off to one decimal place)

In this case, motivation may play a significant role, participants were not rewarded for their efforts played in the game and hence may have lacked the necessary motivation or time to carefully read and understand the information before proceeding to make decision. This rationale is supported by the higher performance score in the exam where participants were obliged to put in their best and carefully read and understand all information.

3.2 Hypothesis 2

The next hypothesis question was to test whether highly educated people faced with graphical dynamic effects, can successfully interpret these graphs. In other to test for this hypothesis, we added a multiple choice question based on the 'learning effect sim' to the examination (to ensure full effort). The overall results show some significant improvement in the performance as illustrated by a Wilcoxon signed rank test—comparing the game score to exam score on a person to person basis (see appendix C). The test showed that there was indeed a statistically significant increase in the number of correct answers at the phase of the exam as compared to the game phase, $p<0.001$ with a medium effect size ($r=0.27$). Confirming that under exam Pressure/conditions students generally pay more attention to case descriptions and choices than in other conditions (learning environments included). Regardless of the better performances in the exam compared to the game, the overall results in the exam were still below optimal (56% incorrect and 44% correct) , this may indicate that even with a high level of education people faced with graphical dynamic effects still find it difficult to interpret such graphs .

Table 2: Results from a cross tabulation of the game performance in relation to the exam performance.

Game Score * Exam_answer Crosstabulation

			Exam_answer		
			Incorrect	correct	Total
Game Score	Incorrct	Count	62	44	106
		% within Game Score	58,5%	41,5%	100,0 %
		%within Exam_answer	84,9%	75,9%	80,9%
		% of Total	47,3%	33,6%	80,9%
	correct	Count	11	14	25
		% within Game Score	44,0%	56,0%	100,0 %
		%within Exam_answer	15,1%	24,1%	19,1%
		% of Total	8,4%	10,7%	19,1%
Total		Count	73	58	131
		% within Game Score	55,7%	44,3%	100,0 %
		%within Exam_answer	100,0%	100,0%	100,0 %
		% of Total	55,7%	44,3%	100,0 %

NB: This table matches the number of people whom had played the correct and incorrect strategy in the game against the exam answers (correct/Incorrect). Here we used the percentage of total row for our analysis.

3.3 Hypothesis 3

To test whether people show better performance after having made a model about the learning curve (specific modelling experience) we developed a cross tabulation matching modelling experience against game performance. The results were very surprising and counter intuitive, it appears that of those whom had some modelling experience with the learning curve , a majority of them performed poorly in the game phase (78%) and only about 22% had it correct, whereas of those that had no modelling experience , 73% performed poorly in the game and 26% played the correct strategy (see

Table 3). This means that only about 5% more) participants performed better without prior experience modelling the learning curve than those with such experience. More research into these strange results is required for further analyses.

Table 3: Comparison of game performance and learning curve modelling experience in modelling learning effects.

Game score * Model_Experience Crosstabulation

			Model_Experience		Total
			No	Yes	
Game score	Incorrect	Count	41	11	52
		% within Model_Experience	73,2%	78,6%	74,3%
		% of Total	58,6%	15,7%	74,3%
	correct	Count	15	3	18
		% within Model_Experience	26,8%	21,4%	25,7%
		% of Total	21,4%	4,3%	25,7%
Total		Count	56	14	70
		% within Model_Experience	100,0%	100,0%	100,0%
		% of Total	80,0%	20,0%	100,0%

NB: This table matches the number of people whom had played the correct and incorrect strategy in the game against the modelling experience of the participants ('yes' means with experience and 'no' without experience). Here we used the percentage within model experience as we want to know the score within this variable.

Given the overall performance of the participants across all the tests, there seems to be an urgent need for model-based decision support because people when faced with (even simple) dynamic effects simply cannot make good estimations. Policy makers may perhaps need to be given the solutions to a problem (if possible) before they make decisions. Providing further assistance, for example through what (Kopainsky et al 2011) suggests in providing a help navigation system or an animated pedagogical agent , which might have even greater impact than providing information like we did via information transparent interfaces.

4. Concluding Remarks and Future steps

Although our results were not statistically significant, they were sufficient to suggest modifications to our methodology and research. Solutions may be provided to participants prior to the decision making phase and the learning environment may be incorporated into a serious examination environment for evaluation purposes. This experiment was part of a suite of simulation games to be carried out in phases. Our next goal with this experiment was to test for decisions under uncertainty and complexity; however in view of this results, as at the simplest level providing information about structural effects does not guarantee that learners perform better, it may not be wise to proceed to even more complex versions of the simulation, where uncertainty and other multi-player activities come to play. We plan to further investigate more interactive strategies, which can help us to effectively test hypothesis related to inertia in the built environment.

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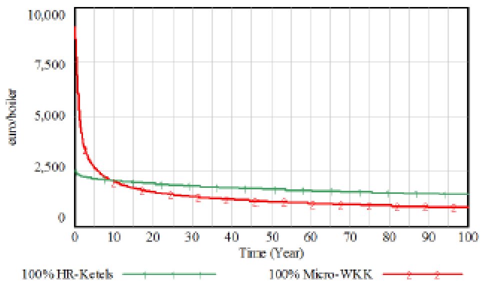
Appendix

Appendix A : Multiple Choice Questions

As manager of a large Dutch housing corporation, you must decide on the types of boilers that will be installed by the housing corporation in the next 100 years. Suppose you can only choose from two types of boilers: HE-boilers or micro-CHP installations. Micro-CHP installations are still very expensive to buy, €9100 per unit (one unit corresponds to one boiler), but recent cost reductions have been spectacular. Experience with micro-CHP so far, 20000 micro-CHP units in total, shows that the '*progress ratio*' equals 0.75. HE-boilers nowadays only cost €2500 because of years of experience (equivalent to 7.5 million installed HE-boilers), and are characterized by a '*progress ratio*' of 0.75 too.

The graph below shows a perfect prediction of the cost reduction of both types of boilers if all 14 million boilers to be installed in the next 100 years by your housing corporation are either of the micro-CHP type (red curve) or of the HE-boiler type (green curve). The red curve is much steeper because micro-CHP is new and there is still much room for descending the learning (hence the marginal cost) curve.

The 'learning curve effect' is the relationship between production costs and the cumulative production over time: the *progress ratio* provides insight into the cost reduction for each doubling of cumulative production. So, if a boiler has a progress ratio of 75% and it costs €10000 to produce the 1000th unit, then it will cost €7500 to produce the 2000th unit.



The red curve (or green curve) in the graph is thus the perfectly predicted production cost per micro-CHP device (or boiler) if you install 100% in micro-CHP (or HE-boilers) the next 100 years. Note: the surfaces between the curves provide insight into the cumulative cost advantages of one technology over another.

Suppose that you are the only one installing boilers (hence, the destiny of your housing corporation is fully under control), and the future is perfectly predictable (no surprises, perfect foresight), and discounting is not required (€1 now is worth as much as €1 in 100 years and at any time in between), which of the following strategies minimizes the total investment costs over the full 100 years (or 14 million boilers)?

a. 100% in HE-boilers: HE-boilers are cheaper and will always be cheaper

b. 100% in micro-CHP: the surface area to the right of the intersection point is much larger than the surface area to the left

c. 100% HE-boilers for the first 10 years and 100% micro-CHP afterwards in order to take advantage of the lowest cost over the full 100 years

d. not 100% in HE-boilers nor 100% in micro-CHP, but somewhere in between (which could be calculated), in order to fully profit from the evolution of both technologies.

Appendix B: Independent sample test comparing the game score for participants in game 1 (with information and game 2 (without information)

Appendix C : Results form a Wilcoxon signed rank test—to compare the game score to exam score

Group Statistics

	Game number	N	Mean	Std. Deviation	Std. Error Mean
game score* 1 means passed 0 means not passed	with information	62	,23	,422	,054
	without information	69	,16	,369	,044

Descriptive Statistics

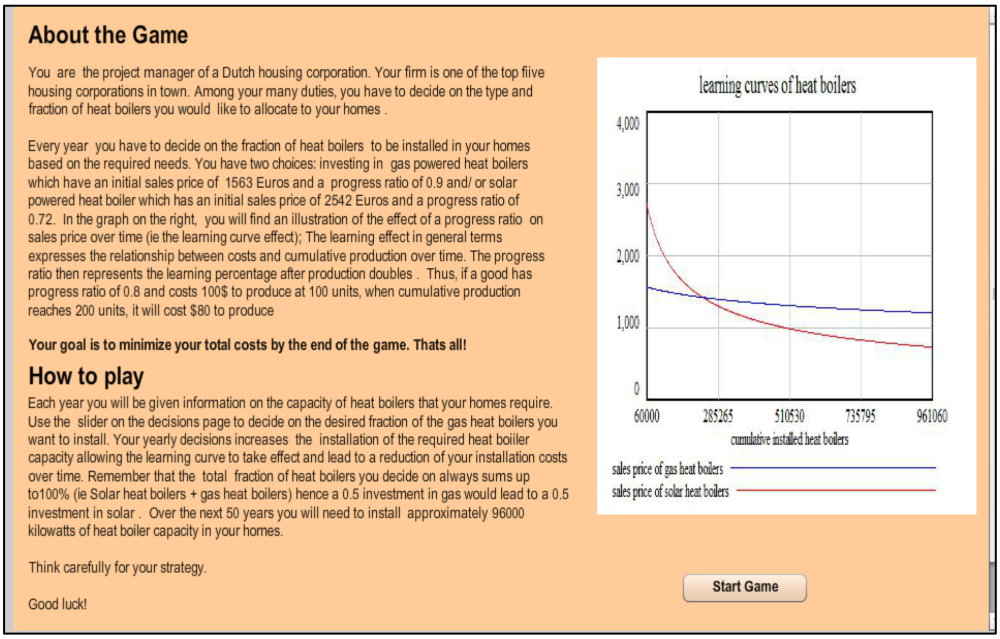
	N	Percentiles		
		25th	50th (Median)	75th
Game Score	131	,00	,00	,00
Exam answer	131	,00	,00	1,00

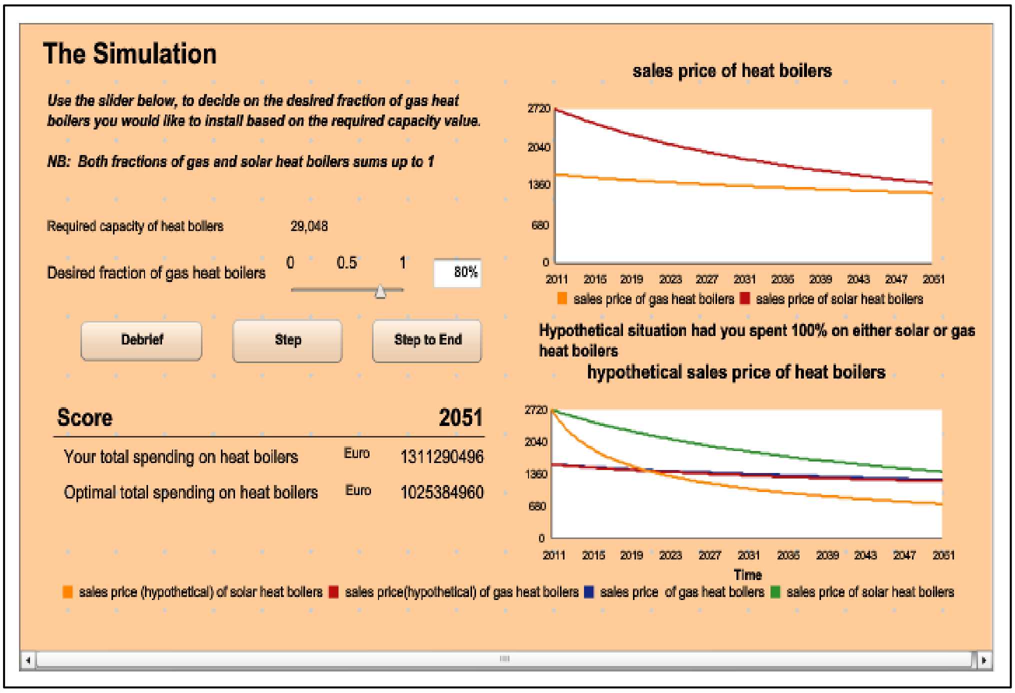
Test Statistics[b]

	Exam_answer - Game Score
Z	-4,450[a]
Asymp. Sig. (2-tailed)	,000

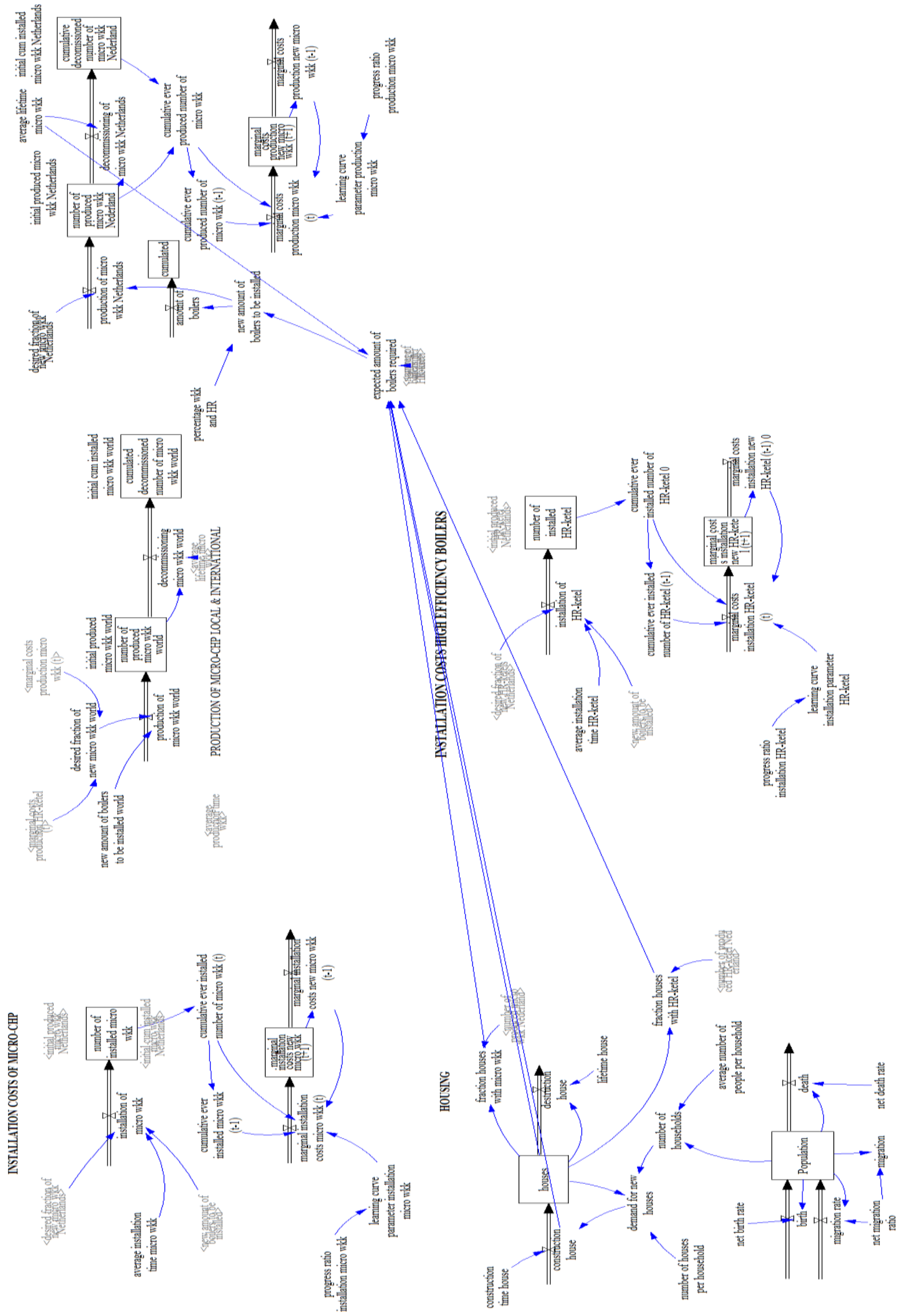
a. Based on negative ranks.
b. Wilcoxon Signed Ranks Test

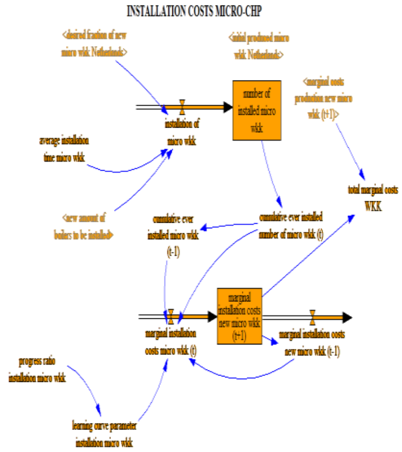
Appendix D : Simple interface of the learning effect simulation (version 1)

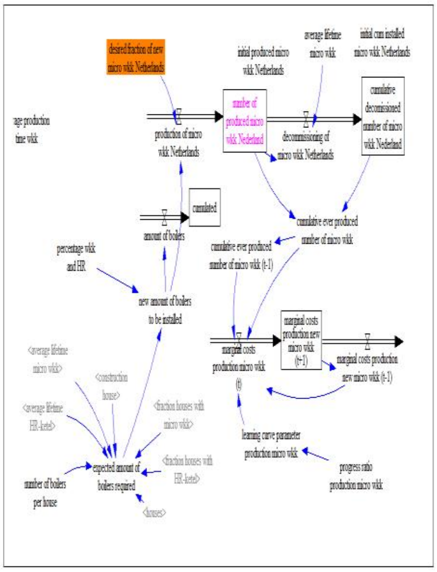




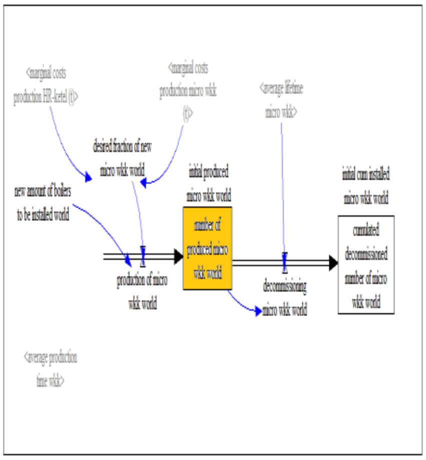
Appendix E: Full SFD underlying the Learning effect Simulation interface

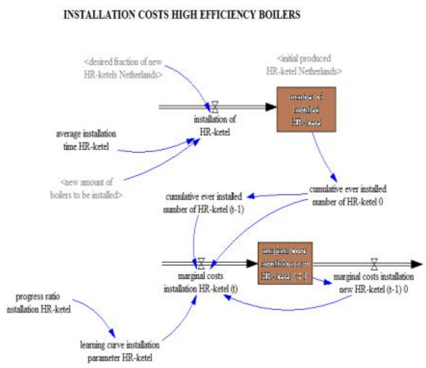

INSTALLATION COSTS OF MICRO-CHP
PRODUCTION OF MICRO-CHP LOCAL & INTERNATIONAL
INSTALLATION COSTS HIGH EFFICIENCY BOILERS
HOUSING



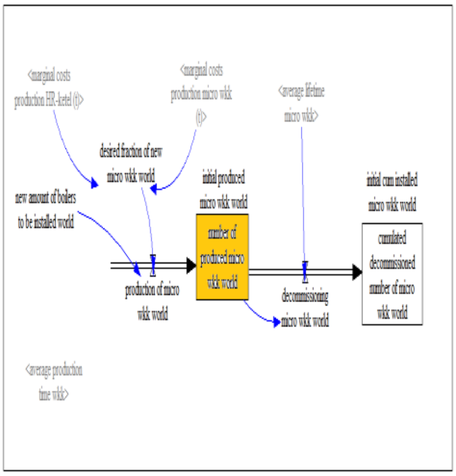


Submodel (a): Installation costs Micro-CHP   Submodel (b) : Production of Micro-CHP in the Netherlands

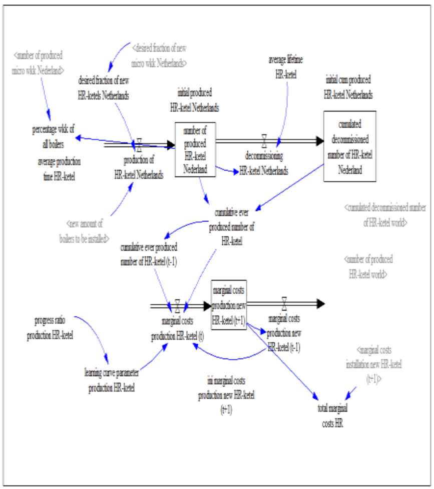




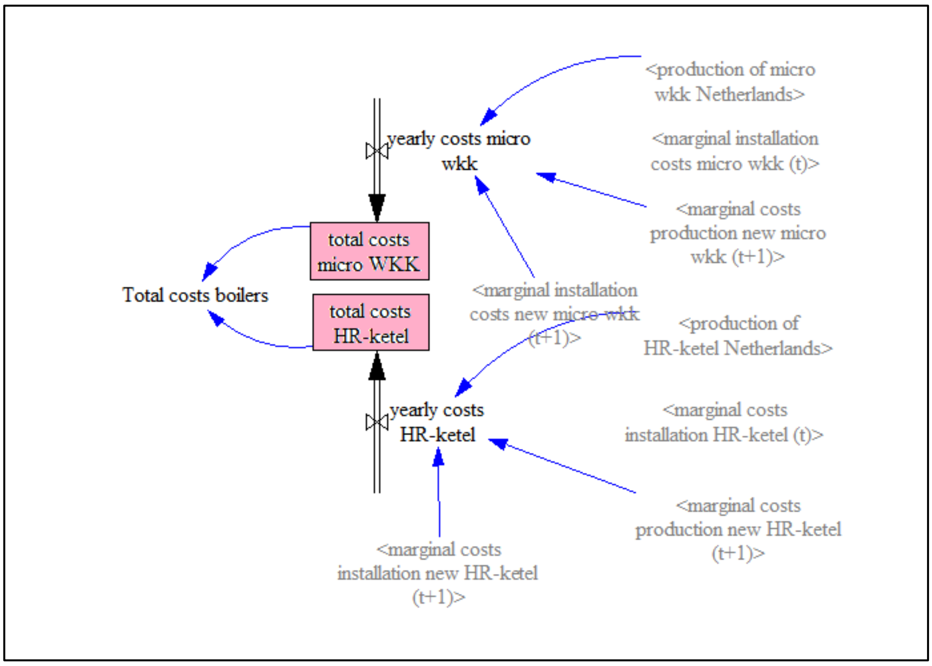
Submodel (c) :Production of Micro-CHP, World   Submodel (d) : Installation costs; HE Boilers



Submodel (e) : Production of High Efficiency Boilers World



Submodel (f) : Production of HE Boilers, The Netherlands



Submodel (g) : Calculation of Total Costs Micro CHP + High Efficiency Boilers