A power game: simulating the long-term development of an electricity market in a competitive game

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***Abstract*—An electricity market simulation game was developed to help students, market analysts and policy makers understand the short and long-term dynamics of electricity markets. In the game, small groups of participants play the roles of competing electricity generation companies. They need to bid their electricity into a power exchange and decide about investing in generation plant. They operate in an uncertain environment, not only because they do not know their competitors' strategies, but also because fuel prices, wind and the availability of power plant vary. In the game, a full business cycle is simulated, so participants experience the effects of their investment decisions. A first extension of the game is a CO_2 market, which effectively changes the rules of the game midway. This way, players learn to analyze the impacts of policy instruments and policy uncertainty upon investors. Early experience indicates that the simulation game creates a high level of involvement by participants, that results in much deeper insight than more traditional didactic methods. The improved understanding that the game provides can also be used to convey insights in related topics, such as variations of the policy measures that were modeled in the game.**

I. Introduction

ELECTRICITY markets exhibit complex dynamic behavior. Short term markets are highly volatile due to the paucity of storage options for electricity. The long lead times and life cycles of power plants and networks, combined with the complexities of imperfect competition and uncertainty due to unpredictable fuel prices and policy changes, pose significant challenges to the analysis of the long-term behavior of electricity markets. Teaching about this dynamic behavior – whether teaching students the basics or communicating to policy makers and strategists the possible consequences of new policy measures – is difficult. Qualitative or static analyses do not fully convey the message, whereas the results of dynamic models are difficult to understand for people who were not involved with creating such models themselves.

A solution was found in the form of a simulation game in which participants play the roles of power generation companies during a number of years. By trading and investing in a fictitious electricity market, players in the game experience what it is like to trade and make strategic decisions in a competitive environment with an uncertain future. Participants also gain insight in when private decisions do and do not coincide with the public interest. The game can be used for understanding existing power markets as well as learning about the behavior of new or intended policy interventions such as a CO_2 market.

The game originated from classroom exercises in which students were asked to bid competitively into a power exchange (an organized market in which electricity is traded), given a certain power plant portfolio. While classroom explanations of the rationale of marginal cost bidding were never met by many questions, at exams students tended to be confused as to why anyone would offer his product at a price below the full cost of electricity generation. The classroom bidding exercise effectively demonstrated why competition tends to force prices down, but left the question open how they would recover their investments.

However, when the exercises were extended to include investment in power plants, significant complications arose. Keeping track of all players' costs and revenues for every round required a large amount of administration by the game operator (teacher). Therefore a software tool was developed. As in the case of bidding, investment decisions appear more difficult to participants when they have to make them themselves, not knowing competitors' plans, future electricity demand or future fuel prices. The simulation game lets participants experience the dilemmas of investing in an uncertain environment. Its positive effects were immediately clear from the substantial improvement in students' answers to test questions regarding how electricity market prices were formed and how investment decisions were made.

The online simulation package effectively performs all administrative tasks for the game operator. As a consequence, he can concentrate on analyzing the game while it is being played and on coaching the participants, where necessary. In addition, the game operator writes a news bulletin that appears on the players' web pages. The news items provide some degree of insight into future energy price developments and a partial analysis (based on 'public' data only that is available to all participants) of what is happening in the market in the game.

An important advantage of playing the game online is that it can be played outside the classroom. As a result, only a limited amount of contact time needs to be spent on the introduction and, at the end, the evaluation of the game. Participants play the game from their own computers at work or at home. This can be done parallel to a class, in the course of a number of weeks. Thus the game is a complement, rather

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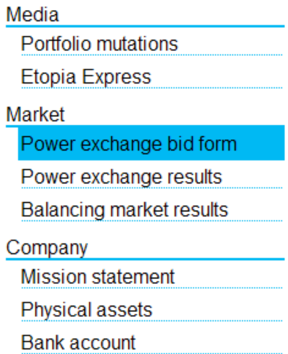


Figure 1: Menu of player interface

than a substitute, to existing coursework or trainings. It is also possible to play the game in a more concentrated mode, for instance during a training of one or several days, in which short series of rounds are followed by periods in which the participants can analyze the results and work on the bidding and investment strategies.

In this article, we will describe the simulation game that we developed and discuss its strengths and weaknesses and plans for future development, including the challenges that we face.

II. The Game

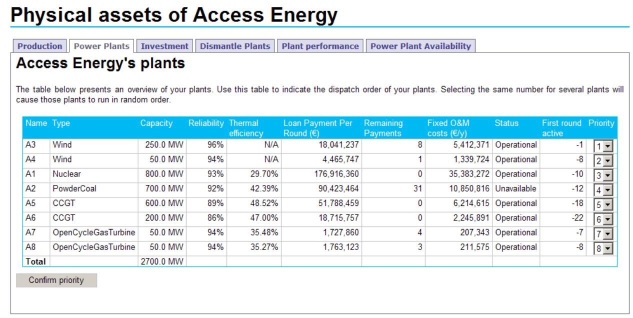
A. The players: competing power companies

Five power generation companies compete with each other by generating and selling electricity. Usually, two to three participants together play the role of one power company. This way, they can share the work, while an important didactic benefit is that this stimulates discussion about bidding and investment strategy among them. The game is played in rounds, each of which represents a year. A long period, e.g. two decades, is simulated in order to give the players insight in the long-term consequences of their actions. Each round, companies offer electricity to the power exchange and decide whether to build new power plants and/or to dismantle old ones.

Each company has its own website, part of which provides public information, such as news and market prices, and part of which contains private information, such as the company's assets and its bank account. Figure 1 shows the menu of a player's interface. Players sell their electricity to the power exchange by filling out bid forms on their web interfaces which state how much electricity they are willing to produce for which price. Investment decisions are submitted similarly the company's web pages. At the end of each round, the market is cleared and players' web pages are updated with information such as which plants ran, how much power they sold, their revenues and their costs. The winning criterion is the bank balance at the end of the game: since all companies start with the same balance, the company with the highest end balance has achieved the highest return on investment.

B. Physical assets: power stations

The basis of each company is formed by its physical assets,


Physical assets of Access Energy

Production | Power Plants | Investment | Dismantle Plants | Plant performance | Power Plant Availability

Access Energy's plants

The table below presents an overview of your plants. Use this table to indicate the dispatch order of your plants. Selecting the same number for several plants will cause those plants to run in random order.

Name	Type	Capacity	Reliability	Thermal efficiency	Loan Payment Per Round (€)	Remaining Payments	Fixed O&M costs (€/y)	Status	First round active	Priority
A3	Wind	250.0 MW	96%	N/A	18,041,237	8	5,412,371	Operational	-1	1
A4	Wind	50.0 MW	94%	N/A	4,465,747	1	1,339,724	Operational	-8	2
A1	Nuclear	800.0 MW	93%	29.70%	176,916,360	0	35,383,272	Operational	-10	3
A2	PowderCoal	700.0 MW	92%	42.39%	90,423,464	31	10,850,816	Unavailable	-12	4
A5	CCGT	600.0 MW	89%	48.52%	51,788,459	0	6,214,615	Operational	-18	5
A6	CCGT	200.0 MW	86%	47.00%	18,715,757	0	2,245,891	Operational	-22	6
A7	OpenCycleGasTurbine	50.0 MW	94%	35.48%	1,727,860	4	207,343	Operational	-7	7
A8	OpenCycleGasTurbine	50.0 MW	94%	35.27%	1,763,123	3	211,575	Operational	-8	8
Total		2700.0 MW								

Confirm priority

Figure 2: Example of a company's power plant portfolio

its power plants. A number of different types of power plant are available. At the start of the game, each company already has a set of power plants such as gas or coal plants or wind farms. Power plants differ with respect to age, size, capacity, fuel efficiency and reliability. The reliability of power plants declines over time. The characteristics of new power plants also change as time goes by: new power plants are more fuel-efficient and cheaper than older ones. In addition to fuel costs, companies need to pay the capital costs of power plants (in the form of loan payments) and fixed operating and maintenance costs. Players receive information about a number of characteristics of their power stations, such as their electricity production per round, the availability of their plant and the price of new plant. Figure 2 shows an example of a company's set of power stations.

Each round, players decide whether to invest in new power plants or decommission old ones. A variety of new types of power plant can be purchased in different sizes. These power plants become slightly cheaper and more fuel-efficient over time. On the other hand, the longer one waits with investing, the fewer rounds the company can enjoy the benefits from the plant. Plants take time to build, from two rounds for a cheap and inefficient open-cycle gas turbine to eight rounds for a nuclear power station.

After a number of rounds, the capital costs of power plants are paid off, but there are also fixed operating and maintenance costs that continue as long as the plant exists. Together with the fact that the operational reliability of power stations declines as they get older, their fixed costs provide an incentive to decommission old plants. Decommissioning provides players with a means to respond to excess capacity, but there is a dilemma because keeping old plants, even if they lose money, can be attractive because they provide the option of quickly increasing output if demand grows or if there are more than average plant outages.

C. Power exchange

The power exchange, which is at the heart of the game, makes use of a 'uniform price auction': all players receive the price of the marginal bid, so the electricity price is the same for all. This is similar to European power exchanges such as the Amsterdam Power Exchange (APX), except that in the game all power is sold through the power exchange and there are no other power contracts (for now – see the intended extensions in Section IV). The design of the power exchange is a compromise between short-term and long-term market elements. On the one hand, it simulates an organized day-ahead market. As wind and power plant availability fluctuate, so does the supply to this market and so do prices. On the other hand, in order to be able to simulate long periods, the 365 times 24 hours of the year are aggregated into three periods: off-peak hours (5000 hours per year), shoulder hours (3600) and peak hours (160), each with a different level of demand. See Figure 3. The reason for these three periods is to provide an indication of the effects of the variations in electricity demand upon the market.

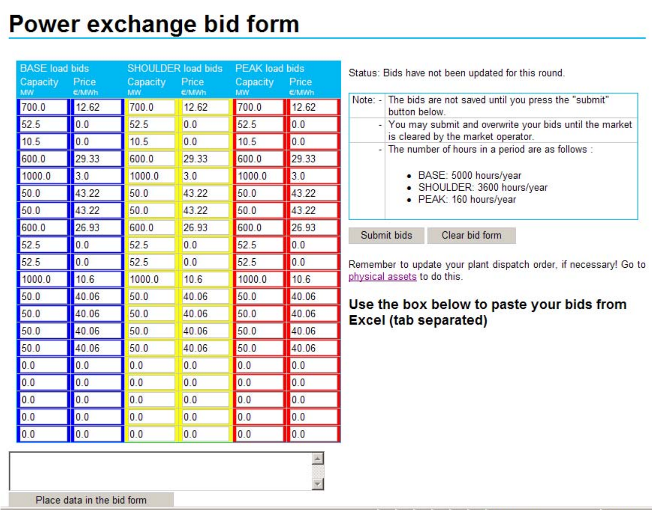
D. Bidding electricity into the power exchange

At the beginning of each round, players see the fuel prices, and the wind factor for that round. The prices of fuels, the availability of wind and the demand for electricity are inputs to the simulation, i.e. exogenous time series. As the players do not know future energy prices, they are a major source of uncertainty. However, from historical time series participants can make assumptions about future fuel prices and the growth rate of demand.

The player web interface also shows the results of the previous rounds: electricity supply and demand functions in the exchange, the electricity prices for off-peak, shoulder and peak hours and the volumes that they sold to the power exchange. Investment plans are published, so players can estimate the future need for new generation capacity.

The first thing that a player needs to do each round is determine his bids to the power exchange. He does this on the basis of the availability and cost structure of the power plants. Players do not know whether the power plants of their competitors are available or off line for maintenance, so they do not know exactly how much generation capacity is available.

They also do not know exactly the level of demand, although historical data that is given to the players provide an indication. This uncertainty is introduced in part to resemble reality and in part because it would otherwise be too easy to manipulate the market.


Power exchange bid form

BASE load bids Capacity MW	BASE Price €/MWh	SHOULDER load bids Capacity MW	SHOULDER Price €/MWh	PEAK load bids Capacity MW	PEAK Price €/MWh
700.0	12.62	700.0	12.62	700.0	12.62
52.5	0.0	52.5	0.0	52.5	0.0
10.5	0.0	10.5	0.0	10.5	0.0
600.0	29.33	600.0	29.33	600.0	29.33
1000.0	3.0	1000.0	3.0	1000.0	3.0
50.0	43.22	50.0	43.22	50.0	43.22
50.0	43.22	50.0	43.22	50.0	43.22
600.0	26.93	600.0	26.93	600.0	26.93
52.5	0.0	52.5	0.0	52.5	0.0
52.5	0.0	52.5	0.0	52.5	0.0
1000.0	10.6	1000.0	10.6	1000.0	10.6
50.0	40.06	50.0	40.06	50.0	40.06
50.0	40.06	50.0	40.06	50.0	40.06
50.0	40.06	50.0	40.06	50.0	40.06
50.0	40.06	50.0	40.06	50.0	40.06
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

Status: Bids have not been updated for this round.

Note:
- The bids are not saved until you press the "submit" button below.
- You may submit and overwrite your bids until the market is cleared by the market operator.
- The number of hours in a period are as follows :
  - BASE: 5000 hours/year
  - SHOULDER: 3600 hours/year
  - PEAK: 160 hours/year

Submit bids | Clear bid form

Remember to update your plant dispatch order, if necessary! Go to physical assets to do this.

Use the box below to paste your bids from Excel (tab separated)

Place data in the bid form

Figure 3: Power exchange bid form

Players need to fill out separate bid forms for each of these periods, offering them the opportunity to bid differently depending on the level of demand. The market results are multiplied by the number of hours, so a company's revenues in one round represent the revenues from an entire year. Figure 4 shows an example of the supply and demand functions during peak hours. The shoulder and off-peak hour markets are the same except for lower demand.

E. Bank account

The third part of the game is the financial side. All revenues and expenses of the companies appear in their bank account: revenues from selling electricity and the costs of each power plant, including fuel costs. The 'stock values' – the winning criterion – of the companies are plotted in the game's news bulletin, so the players can see how well they are doing.

III. EXPERIENCE

A. Competition leads to strong involvement

Playing the game stimulates participants to voluntarily spend significantly more time thinking about short and long-term market dynamics than when they would only receive a lecture – whether or not with discussion – or be asked to perform exercises on these topics. To have a chance of winning, players need to 'reverse engineer' the game, at least in part, by developing a spreadsheet for determining their bids in the electricity market. In some cases, they also use a spreadsheet for estimating the future profitability of new power plants. From actively thinking about a strategy and developing these spreadsheets, trying their strategy and adjusting it in response to how well they do, players learn substantially more than through conventional teaching methods. The reason is clear: the game, with its competitive peer pressure, stimulates participants to be more actively involved, which means that they will retain more of what they learned. This corresponds to earlier experience with simulation games [1].

B. Bidding in a market

Most participants learn the rationale of marginal cost pricing. Through trial and error they also learn the possibilities and limits of influencing the electricity price through bidding higher or withholding generation capacity. Because the price-elasticity of demand is relatively high (the demand function drops 10 €/MWh for each extra MW of capacity), efforts to raise the price lead to such a loss of sales that competitors usually benefit more. Nevertheless some players continue to bid high, not realizing this effect. In this case, the game operator can intervene in the form of a Competition Authority, who investigates allegations of abuse of market power. The Competition Authority first warns involved parties and may eventually fine them if they are found to intentionally abuse their market power. Through this process, that involves private communications with involved

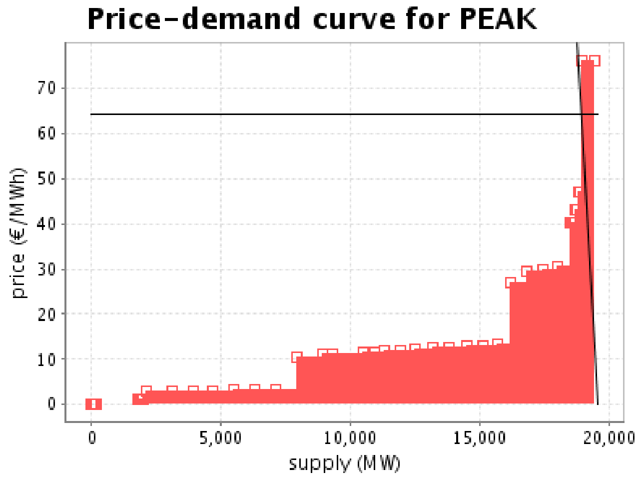


Figure 4: Power exchange results (peak hours)

parties as well as some reporting in the newspaper, the principles of competition policy can be communicated to the players. Such episodes are revisited during the evaluation.

C. Investing under uncertainty

With respect to investment, the participants in the game learn the dilemmas of having to choose when to build which kind of power plant – existing plants are aging, demand is growing – when the relative costs of fuels are highly uncertain. One of the lessons learned is that there is value in waiting with an investment until the need for new plants is more certain, which is a lesson of Real Options Theory [2]. A consequence may be that if everybody waits with investment, a power shortage develops. Figure 5 shows the price development in a game with such an investment cycle. The lead times of the most cost-efficient power plants are long; only inefficient open-cycle gas turbines can be installed in the short term. The high prices of a power shortage may also cause players to overreact, leading to excess supply and low prices a number of years later. Thus players learn about the difficulty of planning in a liberalized market, in which there is no central coordination. They also learn that, contrary to neo-classical economic theory, the interests of the producers and consumers do not converge. In a dynamic and uncertain

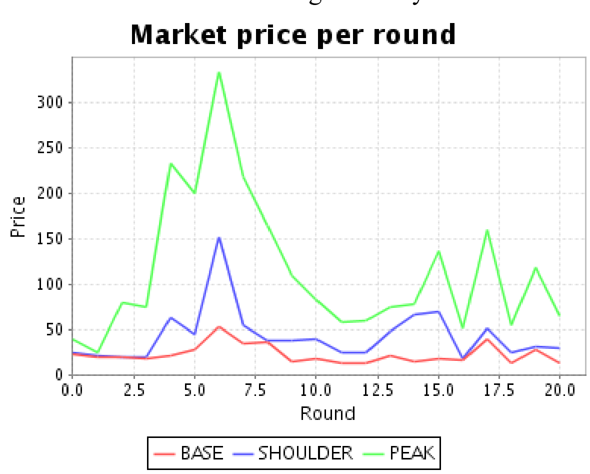


Figure 5: Example of price developments during the game

environment, producers' interest in delaying investment projects until they are more certain to pay off runs contrary to consumers' interest in sufficient generation capacity. As soon as there is a shortage, electricity prices rise quickly, often to many times the cost of generation. These dynamics have been observed in practice, c.f. [2].

D. Game evaluation sessions

A key part of playing a simulation game is the evaluation session at the end of each game. The evaluation session serves three purposes. First, the players would like to see the full picture of what happened, as until then, they only saw part of the game. They like to hear from their competitors what their strategies and reasoning were. During the evaluation session, the participants are asked to explain their strategies and to analyze their strong and weak points. When all players lay their cards on the table, it becomes more clear what happened, and why.

This automatically leads to the second goal of the evaluation session, namely to draw the lessons from the game. By reviewing the bidding and investment strategies of the different players, lessons regarding these subjects can be provided in a much more effective manner than without the game due to their intensive involvement. Participants are challenged to reflect on similarities and differences with reality and to discuss how they would act in reality. In the session, it is analyzed to what extent the events in the game could occur in reality. Discussions focus on bidding behavior – marginal cost pricing versus market power – and on the role of uncertainty and lead times in investment decisions. Often, an investment cycle develops in the game, and it is discussed why and how this could happen in reality and what can be done about it. The perspectives of producers and consumers are compared.

Next, the discussion is be expanded to the role of policies or other aspects of reality that were not modeled in the game – the third goal of the evaluation session. For instance, the discussion could focus on what would happen if some sort of CO_2 or renewable energy policy were implemented, if a price cap were implemented, etcetera. Having played the role of an investor, players can more easily understand the impact of different policies or other changes. The intensiveness with which players experience the game can be used to instill lessons about related topics.

Probably the learning effect occurs when the simulation game is combined with a computer simulation, the results of which are presented during the evaluation session. At one evaluation session we introduced an agent-based model of three versions of an electricity market: without and with a CO_2 market and with a CO_2 tax [4]. In this model, a Monte Carlo analysis was performed of many scenarios for a much larger number of time steps than can be played in the simulation game. Even before this model was mentioned, the participants in the game had raised questions that could be answered with the model. Consequently, they were much more interested in the model and learned more from it than would have been the case otherwise.

We expect that results of such models can be communicated much more easily to policy makers if they have participated in the simulation game first. In the game they would develop an understanding of the dynamic behavior of the model, based on which the scientifically more valid results – and their limitations – of the simulation model can be comprehended. This combination of a simulation model and a simulation game appears to be one of the most powerful ways of informing decision makers – and teaching others – about the dynamic behavior of a system and the possible consequences of changes to that system.

IV. Extensions

The current design of the game is rather basic: players bid in the market and make (dis)investment decisions within a relatively static environment. On the one hand, this proves to be difficult enough. It often takes more than ten rounds before an initial investment cycle has been dampened more or less. Players need this much time – and sometimes more – to learn how to bid efficiently and how to deal with the uncertainties regarding fuel prices, electricity demand, plant availability and competitors' behavior. On the other hand, by that time the novelty of the game has worn off and players' interest wanes due to the routine. We have several plans for improving the game in this respect.

A. CO_2 market

First of all, the current, basic game design provides a basis for adding different policy instruments. The first such policy instrument, a CO_2 market, is currently being developed. This market is a stylized version of the European Union's Emission Trade Scheme. Key is that this market can be implemented in the course of the game, so players experience how the market functions without and with the CO_2 market. The CO_2 market can be added in the middle of a game, effectively changing the rules of the game midway. This, of course, reflects real world in which new policies change the economic profitability of existing and planned assets.

When a CO_2 market is in place, companies need to purchase CO_2 credits before they can emit CO_2. The credits can be purchased each round at an auction. When a company purchases credits, they are added to his CO_2 allowance account. When the company combusts fossil fuels for the production of electricity, the CO_2 emissions are calculated and the corresponding volume of CO_2 credits is taken out of his account. If a company has a deficit of CO_2 credits, it has to pay a penalty and purchase these credits in the next round.

The game's newspaper will be used to introduce the plans to implement a CO_2 market. Key learning goals are the uncertainty regarding when the CO_2 market will be implemented, how high the emissions cap will be and what the effects will be on the costs of electricity production and on electricity prices. It will probably be difficult for players to determine their willingness to pay for CO_2 credits, as this depends on the electricity prices in the next round. Understanding the relations between these two markets is another important goal that will be achieved in this way. Finally, the CO_2 market introduces extra complexity in the decision to build new plants, because future CO_2 prices are uncertain. They will be influenced by the growth rate of electricity demand, investments in CO_2 abatement by competitors and, of course, by changes to the emissions cap.

When there are more than 20 participants in the game, two groups play the game in parallel. This offers the interesting opportunity of applying different policy instruments to otherwise similar game scenarios. In particular, in case of a CO_2 market, the second game instance could be subject to a CO_2 tax. This would be a fee to be paid for every unit of CO_2 emissions. As this would create less uncertainty and fewer complications for the affected companies, it is expected in theory that it would lead to earlier investment in CO_2 abatement. Comparing two game instances will provide an excellent opportunity for evaluating the effects and merits of two policy instruments.

B. Further extensions

So far, the game has been played with much time between different rounds. Typically, two or three game rounds are played each week and the game runs for a number of weeks. The reason for giving player ample time between rounds is to give them time to reverse engineer the game by building their own spreadsheet model. Participants learn much from doing this; in fact, the origin of the game was an attempt to stimulate students to do such exercises. A disadvantage is, however, that the attention may start to wane after a number of rounds.

In addition to the effects of policy changes midway the game (such as the introduction of a CO_2 market), we intend to deal with this issue by creating a function that allows players to bid automatically, so a number of rounds can be played in short succession. This would remove the tedium from standard bidding procedures and limit players' actions to strategic decisions regarding their bids or investments. The idea is to offer participants the opportunity to program a bid function, based on whatever game parameters they choose to use (most likely involving plant efficiency, fuel cost, plant availability, but perhaps also other costs, and allowing for multipliers and add-ons). This way, participants would not need to change anything in response to changing fuel prices, but only if they would want to change their bidding strategy, for instance in response to changes to the capacity reserve margin. We could then agree to run several rounds in short succession, then take a time-out for evaluating the results, and then run another set of rounds. We expect that this would maintain the interest in the game better. A second advantage is that it would be easier to play through a longer time series, for instance when the transition to a more sustainable energy supply industry is being modeled.

Even as the software was being developed, a myriad of other possible extensions and improvements presented themselves, some of which would require substantial programming efforts. Examples are computer agents that offer a range of fuel supply and electricity consumption contracts, different financing options for power plants and uncertainty and cost overruns in plant construction. While these extensions add realism, they also cost the players time to understand. The time invested by players must be balanced by what they learn. Thus there is a tradeoff between the degree of realism and the amount of time that participants need to understand the game.

The many possible extensions raise the question how to design them in such a way that participants get the most out of the game without being weighed down by unnecessary details. Simplifications are acceptable when they do not affect the fundamental behavior of the system and do not conflict with the learning objectives. Because different groups of players have different learning objectives, extensions and improvements should be made modular, so scope and degree of complexity of the game can be adjusted to the audience.

V. Future Applications

A. Policy analysis

While the game has been used for educational purposes so far (providing insights into existing systems), the intention is to also use it for the (ex ante) evaluation of policy instruments. Simulation models are a common tool for this purpose, but sometimes it is difficult to convey their implications to people who are not trained in the use of models. Especially when the objective to provide an understanding of the dynamic relations in a system, written results and static presentations do not easily convey the essence. In a simulation game, participants become part of the system and experience its dynamics first-hand. Especially when long-term goals are concerned, such as reducing greenhouse gases or attracting a certain kind of investment, the simulation game provides a strong experience that results in much deeper insight than more traditional methods. The improved understanding that the game provides can also be used to convey insights in related topics, such as variations of the policy measures that were modeled in the game.

B. Scientific applications

The combination of a simulation model and a simulation game may also have scientific value. The electricity and CO_2 model shows that in case of a CO_2 tax, the lower investment risk causes earlier adoption of CO_2 mitigation measures than in the case of a CO_2 market. This is why we would expect the same to happen in a simulation game, but it would be interesting to see if these expectations are met. If the game corroborates the model outcomes, it can be considered as a validation of the model. If not, the discrepancies will need to be investigated. In case they are not an artifact of the design of the game or of the model, they may point to a need to refine the model. The combination can also be used to 'calibrate' the behavior of agents in an agent-based model. By letting computer agents play in the simulation game and comparing their behavior to that of people, aspects of the agents' algorithms such as investment risk aversion and strategic bidding can be adjusted to mimic observed behavior. Subsequently, these agents can be used in agent-based models that can be made more complex and perform more time steps and (many) more different scenarios than is feasible with people, given their time constraints.

An important challenge is how to validate the effects of the game. From a scientific perspective, the question is to what extent game results tell us something about reality. Players' backgrounds, lectures given before and during the game and information from the game operator all influence the behavior of players. But at the very least, the game may give rise to new research questions that might otherwise have been overlooked.

VI. Conclusion

The electricity market simulation game has already proved its merits, as participants demonstrably learn more about the short and long-term dynamics of electricity markets than they would learn through lectures or other traditional means of teaching. Subjects that appear simple on the blackboard, such as a price equilibrium caused by the different supply and demand functions of sellers and buyers of electricity, are much better understood when players need to perform the actions themselves. Moreover, only then do they realize the difference between a static equilibrium and a dynamically changing situation. A number of improvements and extensions is foreseen for the current game to make it more realistic, to expand its scope and to make it more attractive to play. The simulation game provides a powerful tool for teaching as well as for policy analysis.

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