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Achieving Learning Potentials in an Educational Simulation Game for Trading and Generating Electrical Energy*

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This paper presents and motivates the development of a techno-economic education package, consisting of two simulation games, to simulate both the trading and the generation of electricity in a liberalized market. Six attributes (storytelling; players as problem solvers and explorers; feedback; challenges that fit the student characteristics; competition; appropriate graphics and sounds) are relevant in order for simulation games to achieve their learning potentials. These attributes are identified within both developed simulation games.

Keywords: energy engineering; liberalized electricity markets; simulation game; learning through play

1. Introduction

The way of producing and selling electricity has faced severe changes over the past decades. Electricity markets widely have been liberalized. Before liberalization, companies were typically state-owned, vertically integrated and centrally planned. Unit commitment optimizations were carried out centrally, costs were minimized. The cost-plus remuneration mechanism ensured that costs made would be reimbursed and socialized among the consumers.

After the liberalization, competition has been implemented at the level of both wholesale and retail. Electricity generation companies and suppliers are decoupled from the owners and operators of the high voltage transmission and lower voltage distribution grid. In this context, companies try to sell electricity at a price as high as possible, while trying to produce the electricity that they have sold at the lowest cost. The simulation package developed in this work attempts to represent this twofold goal that electricity generation companies currently face.

The package is developed for the first master year of the energy-engineering curriculum, at the University of Leuven (K.U.Leuven). The master is multidisciplinary and the simulation package combines different elements that are treated in the courses, giving students an overall view of the market environment that has been created in the energy sector. The simulation package provides the understanding of elementary aspects that appear in a variety of courses and is even in itself multidisciplinary in nature. Hence, it is not possible to observe a direct impact on student performance in one specific course. However, identifying and addressing relevant attributes of simulation games, do allow to reflect upon the simulation package and to demonstrate it fulfils the learning potentials. This is the aim of this paper.

The next section of the paper will briefly describe the overall simulation package, consisting of two developed simulation games. The third section will introduce six attributes, required to achieve learning potentials of simulation games. Each attribute will be introduced, and discussed for the two simulation games. A reflection of the students will also be given on each attribute. Section 4 concludes.

2. Description of developed simulation package

The format of a simulation game was chosen, to allow students to get insight in the complex supply chain of electric energy. Other electricity market simulation games exist, see for instance [1–2]. These focus particularly on the pool-based electricity market, with complex bidding mechanisms. The simulation package presented in this paper differs from these references as it considers an electric network in the electricity market and it extends the scope up to actual electricity generation. This section will now briefly describe the developed simulation package.

2.1 Setting of overall simulation package

The objective of the overall simulation package is to

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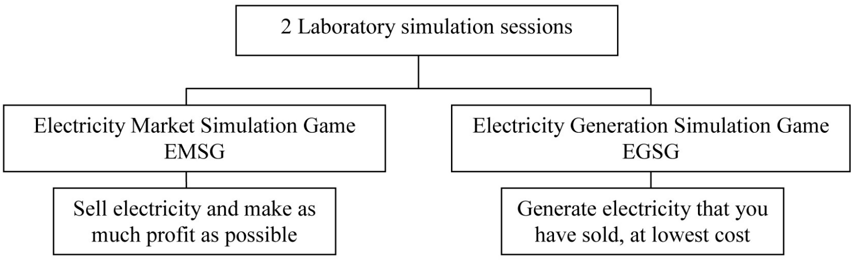

Fig. 1. Schematic overview of simulation games.

make students familiar with both the market as well as the technical aspects of electricity generation. The simulation package developed at the University of Leuven (K. U. Leuven) consists of two separate games: the Electricity Market Simulation Game (EMSG) and the Electricity Generation Simulation Game (EGSG).

Figure 1 presents a schematic overview. The EMSG simulates the sale of electricity on a European power exchange. The EGSG simulates electricity generation with different power plants in order to meet a certain demand (which can be seen as a certain amount of electricity previously sold on the market). This corresponds to the real situation, where electricity is typically traded until the day before delivery. On the actual day of delivery, companies have to generate the electricity that they have committed to, while furthermore facing a number of uncertainties.

The use of the simulation games are built in laboratory simulation sessions (further called 'lab sessions'). Some of the advantages to do this are that the instructors can stimulate the students to refresh their knowledge about the main concepts and that they can clarify to the students not only the rules of the game and the roles of the students, but also the learning goals. The lab sessions are given to students in groups of 15–25, in a computer-equipped classroom, and take each about three hours.

2.2 Electricity Market Simulation Game (EMSG)

In this first simulation game, each student represents a specific electricity generation company. This company has a given marginal cost curve for electricity generation. The goal is to set up adequate bid curves and hence, to maximize profit. The full context of this game will be described further.

The main learning goal of this game is that students know the basic aspects of the operation of the electricity market. They should be able to use the concept of a marginal cost curve and bid curve, and should understand the cost deviating bidding behavior of generation firms and the phenomenon of market power. Furthermore, students should also be able to estimate the impact of network congestion on competition and prices. This simulation game can be used to teach power economics to engineering students, but also to explain economists the effect of congestion on market clearing, or even to train traders in their bidding strategies.

2.3 Electricity Generation Simulation Game (EGSG)

In this game, each student again represents an electricity generation company. This generator faces a certain demand for electricity (e.g., a certain amount of electricity that has previously been sold at the power exchange) and has a fixed set of power plants. The goal of the game is to generate the electricity the company has to deliver at lowest cost. The learning goal of this part of the overall simulation package is to introduce different aspects of electricity generation. Students are made familiar with concepts as unit commitment (UC) and economic dispatch.

A good understanding of the current CO_2 market in Europe, the EU Emission Trading Scheme (EU ETS) and of the functioning of a balancing mechanism, is also part of the objective.

3. Attributes of simulation games

Although very little empirical evidence regarding the impact of gaming and simulations on learning is available [3–4], the literature with regard to game-learning identifies some potential benefits. Games and simulations allow the student to enter complex domains that would otherwise be inaccessible [5]. Students can safely experiment with strategies, manipulate objects in order to test their hypotheses and take decisions that in the real world are irreversible and/or at risk [6–7]. The experiences that result from those experiments enable learners to understand complex concepts 'without losing the connection between abstract ideas and the real problems' [8]. Rather than memorizing the material presented by others, games and simulation allow students to discover new rules and ideas, to create new mental models, to make a scale representation of reality [6–7]. Moreover games can be intrinsically fun to play what directly contributes to learner motivation and through this mediating process to learning itself [4].

In order to fulfil those learning potentials of games, the following 6 attributes of educational games are relevant:

- storytelling
- players as problem solvers and explorers
- feedback
- challenges that fit the student characteristics
- competition
- appropriate graphics and sounds

These attributes are critical in encouraging active engagement, perseverance and high levels of immersion [4].

After the first year of the incorporation of the simulation package into the curriculum (2007–2008) the feedback given by students has been collected under the guidance of one of the authors—connected to the Centre for Educational Development of the university. The collection of feedback from a focus group (as in [9]), allowed to search for the different opinions among the students with regard to the practical application and setting of the package. These data were collected to enable the teaching staff to optimize the simulation package.

Although the data were not collected in order to and do not allow to make some statements regarding the learning effects of the simulation package, the focus group made clear that the students value the simulation games as adequate tools to help them gain insight in the interdisciplinary matter of electric energy.

In the following subsections, the 6 attributes will be explained and discussed for both simulation games. The reflection of students concerning each attribute will also be addressed.

3.1 Storytelling

A narrative creates a meaningful situation and a valued virtual identity for the learner [5]. Furthermore, it creates a psychological reality [4] and integrates the challenges the player faces into a larger task or a problem [7]. Providing a narrative has in that way a positive influence on the motivation of the learner, enhances reflection [10] and allows for the learner to generate contextualized knowledge [4].

3.1.1 Storytelling in EMSG

The narrative of the EMSG is as follows: on the European electricity wholesale market different EU-generation firms offer to supply electric energy in a mandatory auction. Eight countries are considered: Austria, Belgium, France, Germany, Italy, the Netherlands, Spain and Switzerland. The largest fourteen existing generation firms are incorporated in the game: ACEA, AES, EDF, Edipower, Electrabel, EnBW, Endesa, Enel, E.ON, Essent, Iberdrola, Nuon, RWE and Vattenfall. This (European) implementation is only meant as an illustration (fictive), given the fact that in the game one single market is considered with implicit auctioning, not corresponding to the separate markets in reality.

Generation firms own generation capacity (possibly in different countries), and submit bids for generating power in all the countries where they have production capacity. In each country where a certain firm is active, a marginal cost curve is given. This curve consists of a stepwise, increasing function, typically starting at zero (e.g. wind and hydro generation). At higher supply levels, these curves represent the marginal cost associated with coal and gas fired generation while the highest levels represent the marginal costs associated with peak generation such as turbojets. In Fig. 2 (screenshot of

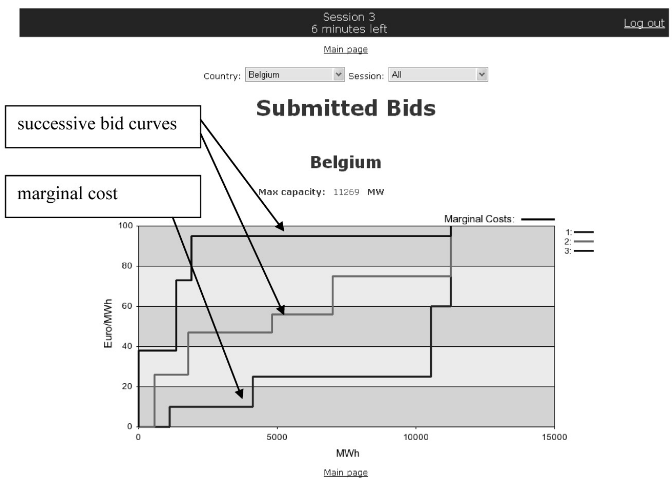

Fig. 2. Screenshot of EMSG, with marginal cost and successive bid curves indicated.

EMSG), the marginal cost curve of a player in one country is indicated.

If there are no network constraints, it does not matter where the orders are introduced. It means that the accepted demand and supply quantities at a certain location can deviate freely, as long as demand equals supply totalized over all locations. If network constraints are taken into account, the difference between supply and demand at a certain location implies an injection in the network (if positive) or a withdrawal from the network (if negative) at that location. These injections and withdrawals or off-takes cause flows that have to be constrained in a limited capacity network.

In order to clear the market, i.e., to determine which orders submitted by the firms are accepted, and which not, a constrained optimization problem has to be solved. This is the so-called market-coupling problem or implicit auctioning problem. It can be solved with standard algorithms (linear programming). The solution determines which orders to accept and at which locational prices the contracts are settled. The prices are determined as the shadow or dual prices of the market clearing condition (i.e., the algebraic sum of injections and off-takes at each location and of the incoming or outgoing power flows must be zero). The DC power flow approximation is used, which is a simplification of the real power flow equations. For the full mathematical description of the market-coupling problem, we refer to [11–12].

3.1.2 Storytelling in EGSG

This game tells the story of electricity generation companies, who have to produce a certain amount of electricity. One could say that the amounts have previously been sold, in a process similar as in the EMSG. Students represent one of those generation companies and have to produce a given amount of electricity in the cheapest way possible.

The game consists of successive modules, with increasing difficulty. Technical characteristics (e.g., minimum operating points, start up costs) are gradually incorporated. As from the 4th module, a carbon market and a balancing market are included.

The carbon market is presented by a single price for CO_2 allowances [euro/ton$_{CO2}$] and is inspired by the currently established EU ETS. Incorporating a cost for CO_2 can change the merit order of power plants.

The balancing market is inspired by the system applied in most European countries, where the Transmission System Operator (TSO) is responsible to keep the balance in its control area. While in reality different players (generators, suppliers, financial players etc.) are grouped in balancing responsible parties and have to be in balance as a group, in the game the generators have to be in balance on their own (produce exactly what you are committed to). In the simulation game, the unbalances of all generators are aggregated and two prices for unbalances are calculated: one price for the generation companies with a surplus (TSO will pay these generation companies) and one price for generation companies with a deficit (these generation companies will have to pay the TSO). The prices for unbalances are determined in such a way that there is an incentive to be balanced. Especially if the overall system is unbalanced in the same direction as the player's unbalance, meaning that the player is worsening the overall system unbalance, there is a high penalty, which is also the common European practice.

In the fifth module, each player has a certain amount of wind power in its portfolio. An imperfect wind forecast is made available for all the hours that are played. In the sixth module, a full UC schedule has to be set up, prior to dispatch and failure rates of power plants are included.

3.1.3 Reflection on 'storytelling'

All students shared the opinion that the simulation games had nice concepts and that playing the games was motivating. The fact that the games were a simulation of the reality certainly contributed to the motivational aspect. One of the students that represented a 'smaller' player (EMSG) had the perception that this was a disadvantage to get insight into the electricity market. Another student did not agree with this statement, stating that he might perceive the game differently, but the insight in the overall market functioning is the same for all students.

3.2 Players as problem solvers and explorers

A simulation game stimulates a student to enter a representation of a conflict or problem situation with an unknown ending. The student is stimulated to solve the problem, to make decisions and to make choices in this situation. This way the game allows the learner to have experiences he can reflect upon; build his model of the reality and have new experiences, as been described by Kolb in his cycle for experimental learning [13]. According to Kiili [7], educational games should provide possibilities for exploring phenomena, testing hypotheses and constructing objects. Reflection is a critical factor in this learning process. Kiili points to games were players keep on experimenting with actions until their scores improve and that those 'trial and error' games do not enhance learning. Herrington et al. [14] stress that the extent to which the task of the student leads to realistic problem-solving processes is a crucial element of educational games. The 'authentic' character of the task will enhance the motivational effects on learners.

3.2.1 Players as problem solvers and explorers in EMSG

Students play the role of a generation firm, which operates in up to three countries. As students get the task to make as much profit as possible, it is up to them to find out how they can affect the price.

During the game, a firm submits bid functions. Once all bids have been submitted, the auctioneer clears the market subject to network constraints. Gains from trade are maximized, given the offers received from the students for delivery at different locations and the demand bids for consumption at each location, which are fixed in the simulation game. Every order has a price and quantity limit.

The auctioneer determines the accepted order quantities based on their orders and those introduced by others. When submitting their orders, firms do not know the orders submitted by their colleagues. Furthermore, the market result only yields aggregated information of the orders introduced by their colleagues. Figure 2 presents different bid curves, submitted by a student in successive rounds of the EMSG.

3.2.2 Players as problem solvers and explorers in EGSG

In each module, the different players (generation companies) have a fixed set of power plants (the same for all players) and face a certain load curve (e.g., 6 periods). The generation companies are asked to dispatch this set of power plants in order to meet demand at lowest cost. They can determine generation of each power plant for each hour.

This game is played in successive modules, with increasing difficulty. In the first 3 modules, dispatch can be determined for the full time span, i.e., all the periods that are simulated. As from the 4th module, the modules are played period by period, since there now exists interaction between the different players as a balancing market is included.

When wind power is incorporated in the portfolio and power plants can face an unexpected outage, generators can deal with this by keeping enough modulating power online to keep their balance.

3.2.3 Reflection on 'players as problem solvers and explorers'

Students point out that a good understanding of the functioning of the market results from the fact that they have to think about problems and actually solve them themselves, rather than someone explaining it to them.

All students enjoyed the concept of simulation games and experienced a high degree of motivation. This motivation resulted partly from the fact that they represented actual companies (EMSG), i.e., they have to act as actual problem solvers. The fact that they can play different rounds or face modules with increasing complexity is also a source of motivation.

3.3 Feedback

In order for students to learn from there decisions and choices made during the game, feedback is an absolute condition. Feedback gives the player information about his or her current level of attainment. By reflecting on this feedback, a student may construct his own model of the situation presented and the way the situation evolves over time. He may also discover new and better ways to solve the problem [7].

3.3.1 Feedback in EMSG

The instructor is the market operator that organizes the mandatory auction where the generators compete to supply electric energy. Several sessions are run so that students can reflect upon previous ones and can interact with their peers or the instructor to improve their profits. Students are allowed to communicate during the game and can make agreements. After every market clearing, every student privately receives feedback regarding his accepted or traded volumes per country and has access to the aggregated information. The aggregated information is made public as illustrated in Fig. 3. This Figure 3 presents the prices per country, together with the cross-border flows. Under the prices, the injections (+) in the network or the withdrawals (–) from the network per location are displayed. Starting from the third session, this aggregated information is a starting point for discussion with the students.

3.3.2 Feedback in EGSG

All six modules of this game are played successively. During the first three modules, the players can optimize their generation for the whole given demand profile. Once every student has finished his optimization, all the data is gathered by the instructor and the module is closed. After each of these modules, the single optimal solution is demonstrated by the instructor and discussed with the students. By including additional constraints in the successive modules, students experience how these constraints affect the optimal solution.

Module 4, module 5 and module 6 are played period by period (as for each simulated period, aggregated data of all students is required to determine the unbalance prices). As soon as all students have decided upon their generation for the current period, all data is aggregated by the instructor.

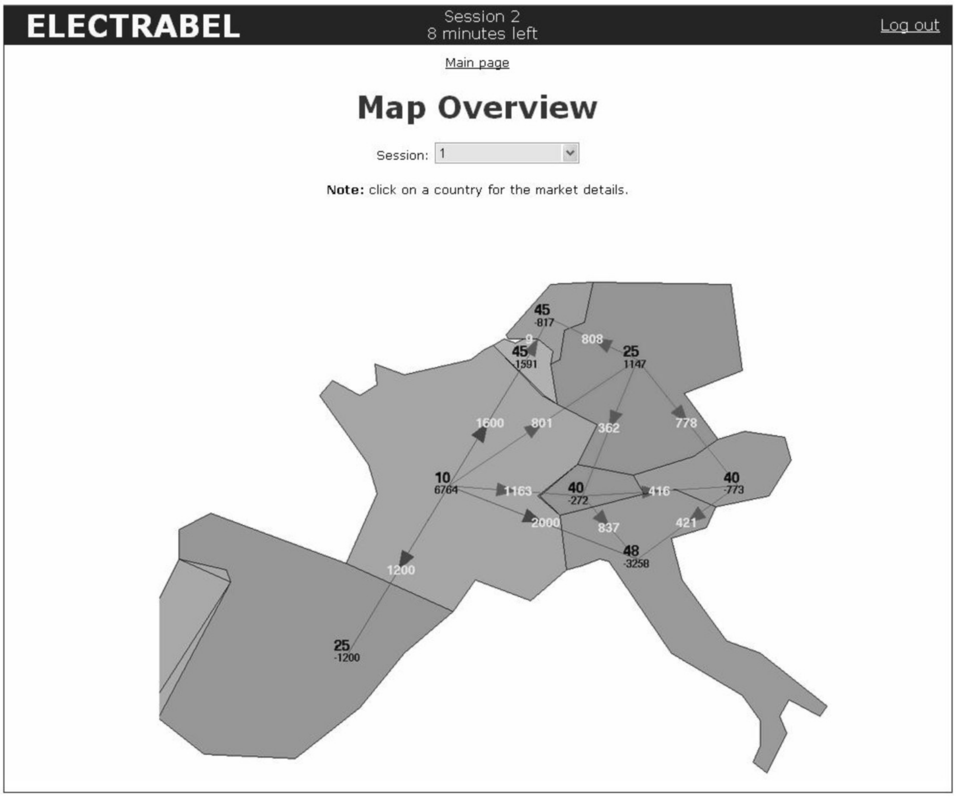

Fig. 3. Example of results made public after market clearing. Prices and quantities are presented for all countries, together with cross-border flows.

Unbalance prices are calculated and made public to all players when the next period is played.

The developed lab sessions allow the instructors to give extra feedback to the students and to discuss the results of the game. By making the experiences of the students explicit, by inviting the students to reflect upon them, by relating them to the learning goals and by linking the experiences with the relevant concepts and theories, the learning of the students is enhanced. By sharing the experiences the creation of a shared mental model is stimulated [6].

3.3.3 *Reflection on 'feedback'*

Students have the impression that fully understanding all the concepts is only possible with help from the instructors. This help is identified as individual feedback, feedback towards the whole group, and referring to the introductory explanation throughout the entire lab session. The low threshold between instructors and students makes communication easy. The visual personal feedback built in the games was also valued by the students and helped their understanding.

3.4 *Challenges that fit the student characteristics*

The challenges a player is confronted with depend on how well tasks are structured, on the degree of user choice and on the complexity and 'realistic' character of the situation. Ill-structured problems, a wide range of user choices and a high realistic character are valued regularly because of their potential positive influence on motivation. In [4, 7], however, it is stressed that challenges presented by a game should be closely matched with the players' skill level. Challenges that are too high will lead to anxiety, while challenges that are too low will lead to boredom. Playing the game, however, enhances the players' skill level. In order for the learner to keep on learning new strategies the structuring of progressively more difficult tasks [5] or even an adaptation of the tasks to a player's behaviour might be a good solution [7]. In turn, this will lead to a sense of competence and enhances the players' motivation to learn.

3.4.1 *Challenges that fit the student characteristics in EMSG*

In the first session of the EMSG, students are asked to submit their marginal costs. It is explained to students that this is the solution under perfect competition and that they should try to improve their profits by interacting with each other. Engineering students are not always familiar with the (economic) concept of market power, i.e., the ability to profitably control prices. As the simulation game progresses, students increasingly start to notice that they can exercise market power. Their behavior does, however, never fully converge to what could then be called the equilibrium solution of the simulation game.

The instructor can lower or raise the time students get per clearing session. This allows for the instructor to build in more complexity, depending on the skill level reached by the students while playing the game.

3.4.2 Challenges that fit the student characteristics in EGSG

In contrast to the EMSG, the EGSG is played gradually, with an increasing level of complexity. The basic principle is the same in each module: produce a certain amount of electricity (over time), at lowest cost, given a fixed power systems and respecting the technical constraints of the given power plants.

Dependent on the module, additional features are present:

- Module 1: Power plants have a simplified (convex) cost curve;
- Module 2: Power plants have a minimum point of operation and a corresponding cost curve;
- Module 3: Module 2 + startup costs are considered;
- Module 4: Module 3 + balancing and CO_2 market are present;
- Module 5: Module 4 + wind power is included in players' portfolio;
- Module 6: Module 5 + full UC schedule + possible outages of power plants.

In the EGSG, the instructor can also vary the time students have for dispatching their power plants, to keep an adequate level of difficulty and challenge.

3.4.3 Reflection on 'challenges that fit the student characteristics'

Students indicate that they have sufficient prior knowledge in order to play the simulation games. Most concepts introduced by the simulation games are not new for them. However, students indicate a better understanding of these concepts, after playing the simulation games.

The majority of the students also have the impression that it would be more meaningful to play the games in pairs rather than alone. This would enhance discussion.

The students advocate for even more complexity in both games, not in the beginning of the games, but at the end. They even gave multiple suggestions to do so.

3.5 Competition

Building some elements of competition in the game, either against oneself or against other players, may also influence motivation by heightening a sense of accomplishment and efficacy, what in turn will lead to enhanced learning results [4].

3.5.1 Competition in EMSG

Students represent actual companies and their only goal is to make as much profit as possible. Actions and decisions of a certain player can have a direct influence on the outcome (price) in a certain country, and/or on the power flows between countries. This setting creates an atmosphere where every student wants to perform as good as possible and make the highest profit. Furthermore, students are allowed to interact and to communicate, in order to make deals or group together in cartels to affect the price.

3.5.2 Competition in EGSG

In each module, students have to generate an amount of electricity at lowest cost. After each module of the EGSG, a top 3 ranking of the students who performed best during that module is revealed by the instructor. When students perform equally well (e.g., determine the optimal solution), students are ranked according to the time needed to submit their solution.

3.5.3 Reflection on 'competition'

The students indicate that they like the competition aspect of the games, that it serves as a real drive to perform as good as possible and that it motivates them to actually think problems through.

3.6 Appropriate physical representation

According to Kiili [7], finding a balance between attractive elements and educational objectives when designing a game, is very important. Attractive elements can enhance a learner's motivation. However, if those elements require too much cognitive activity from the learner in a way that hinders rather than stimulates the achievement of the learning goals, this poses a problem. Graphics, sounds and artefacts should be appropriate for the players skills. Wideman et al. [4] reason that not the physical reality of the learning situation is of importance, but the psychological reality this situation has for the student.

3.6.1 Appropriate physical representation in EMSG

An example of the interface of the EMSG is presented in Fig. 2. Players can enter their bids numerically, or can choose to click and drag the lines of

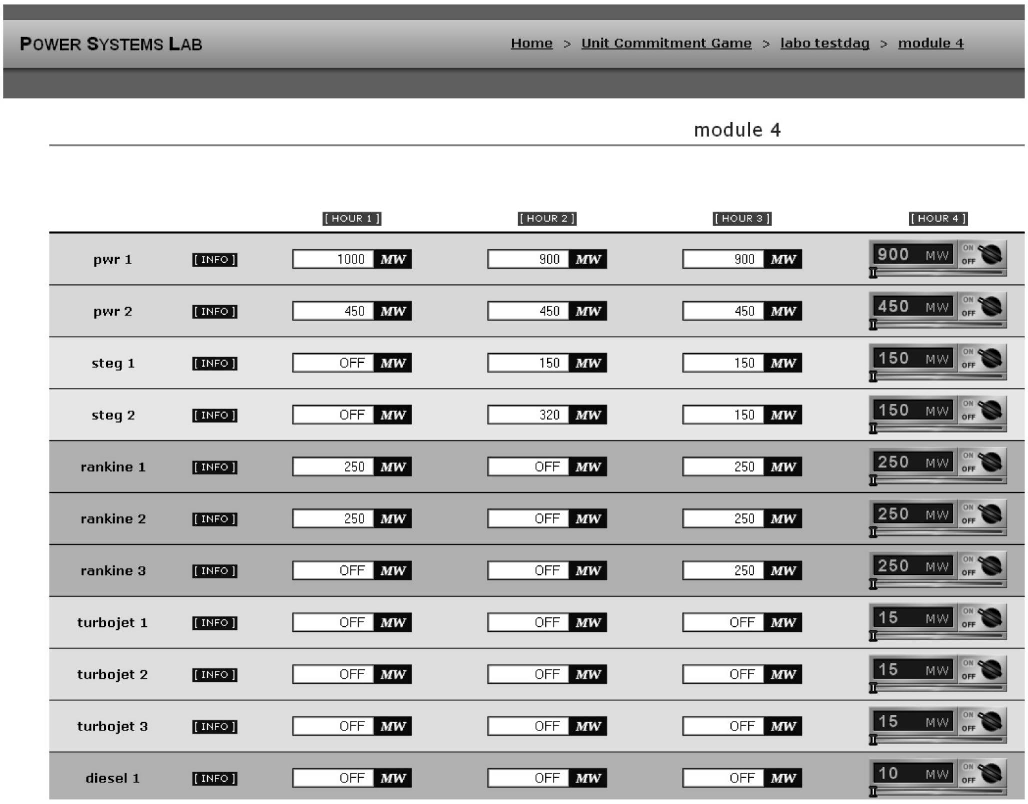

Fig. 4. Screenshot (1) of the interface of the EGSG, reflecting the input spreadsheet.

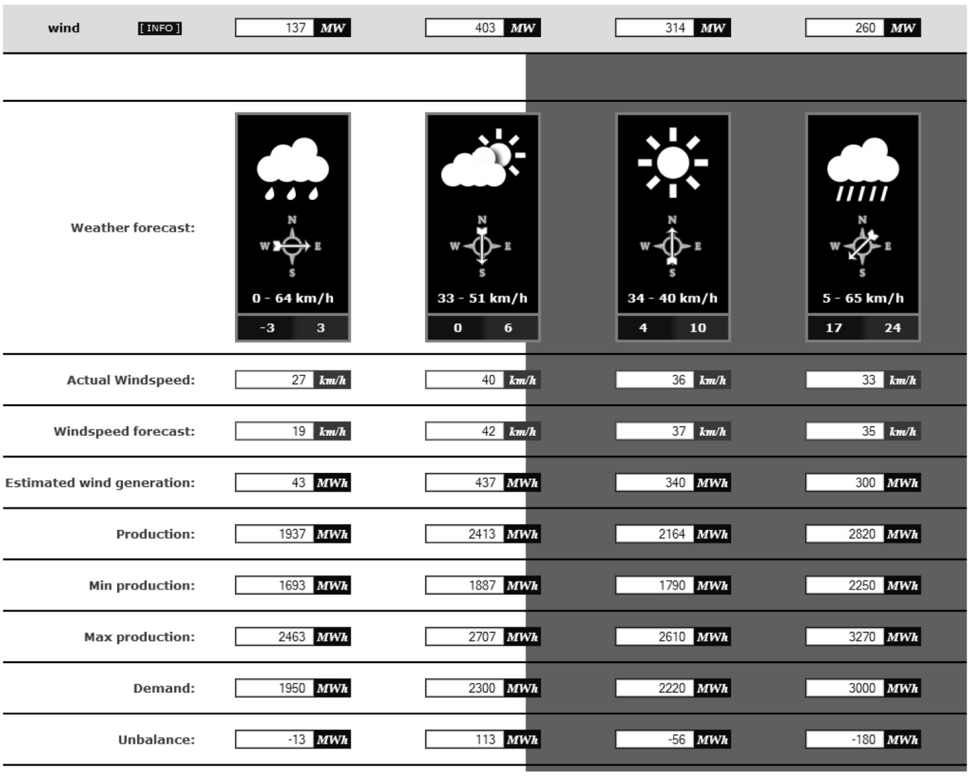

Fig. 5. Screenshot (2) of the interface of the EGSG, with part of the outcome.

their submission curve. Figure 3 presents an example of the results that are made public after a market clearing. It also reveals the quantities sold in each country, together with the price. The flows on the interconnections are also revealed, with congested lines marked in red.

3.6.2 Appropriate physical representation in EGSG

Figure 4 presents an example of the interface of the EGSG, reflecting a spreadsheet of power plants, where players can modulate the power generated by each power plant. It is possible to get detailed information of each power plant, or to get a full detailed view of the period that is being played. Figure 5 presents a second screenshot of the EGSG, now reflecting part of the outcome.

3.6.3 Reflection on 'appropriate physical representation'

The interfaces for both games were very much appreciated by students. Some suggestions for minor improvements were made and will be taken into account towards the future development.

4. Conclusion

The electricity industry is demanding an increasing number of energy engineering students with knowledge of the functioning of liberalized electricity markets. One way to develop this knowledge is by means of a simulation game. This paper describes the development of laboratory simulation sessions for that purpose. During these sessions students play two simulation games: EMSG and EGSG.

In the EMSG, students are made familiar with trading strategies. They are exposed to the functioning of the liberalized electric energy market and develop a feeling of the important role of the transmission network in this market.

In the EGSG, typical aspects of electricity generation are dealt with. Students optimize the generation of electricity, subject to technical constraints of power plants (modularly increased difficulty). A carbon market is introduced and concepts of balancing are included.

Six attributes are identified as being crucial for simulation games to achieve possible learning potentials: storytelling; players as problem solvers and explorers; feedback; challenges that fit the student characteristics; competition; appropriate graphics and sounds. For each of these attributes, the relevant features of the developed simulation games have been identified. All six attributes are demonstrated to be present, which is also confirmed by the perception of instructors and students. Nonetheless some of the attributes could be optimized; one can conclude that this simulation package is able to fulfill its learning potentials.

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