

**REPUBLIC OF TURKEY
ERCIYES UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED
SCIENCES
DEPARTMENT OF ENERGY SYSTEMS ENGINEERING**

ELECTRICITY MARKETS SIMULATION GAME



**Prepared by
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**Supervisor
Asst. Prof. Saltuk Buğra SELÇUKLU**

M.Sc. Thesis

**July 2020
KAYSERİ**

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COMPLIANCE WITH SCIENTIFIC ETHICS

I declare that all information in this study is obtained per academic and ethical guidelines. I also state that I have fully cited and referenced all materials and results that are not unique to this work as required by rules.


Ishmael Coffie ABUSAH

Signature:



COMPLIANCE WITH DIRECTIVE

The study “**Electricity Markets Simulation Game**”, an M.Sc. thesis, has been prepared under Erciyes University Postgraduate Thesis Proposal and Thesis Writing Directive.



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The study entitled “**Electricity Markets Simulation Game**”, which is prepared by **Ishmael Coffie ABUSAH** and supervised by Asst. Prof. Saltuk Buğra SELÇUKLU, is accepted as an **M.Sc.** thesis at Erciyes University, Graduate School of Natural and Applied Science, Department of Energy Systems Engineering by the jury.

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ELEKTRİK PİYASALARI SİMÜLASYON OYUNU

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Yüksek Lisans Tezi, Temmuz 2020**

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ÖZET

Geçtiğimiz yüzyılda, elektrik üretimi, iletimi, ticareti ve son olarak tüketicilere dağıtımını devletler tarafından kontrol edildi, başka bir deyişle, piyasa tekelleştirilmişti. Bu düzenlenmiş sistem, tüketicilere kamu hizmetlerini seçme seçeneği sunmaz. Bu nedenle yetkililer tarafından kendilerine uygulanan fiyata mecburdurlar. 20. yüzyılın sonunda, elektrik sektörünün serbestleşmesinin başlamasıyla birlikte, bağımsız elektrik üreticilerinin pazara girişi serbest bırakıldı. Böylece, müşteriler için daha ucuz fiyatlar ve daha kaliteli hizmetler sunan rekabetçi elektrik piyasaları ortaya çıkmıştır.

Ancak, rekabetçi elektrik piyasası, gelişmeye devam eden ve karmaşık doğası nedeniyle, yeni öğrenciler ve profesyoneller için sistemi anlamada zorluklar yaratmaktadır. Bu öğrenme sorununun çözümüne yardımcı olmak için, bu çalışmada PHP ve JavaScript gibi web programlama dilleri kullanılarak, web tabanlı bir simülasyon oyun platformu geliştirilmiştir.

Oyunun başarısını test etmek amacıyla, oyunu oynayan öğrencilere bir anket sunuldu. Öğrencilerin simülasyon oyununu kullandıktan sonra öğrenmelerinin yaklaşık %95 oranında arttığı görülmüştür. Simülasyon oyununun kullanıcılara sağladığı uygulamalı eğitim ortamı sayesinde, karmaşık kavramlar daha kolay anlaşılabilmiştir.

Ayrıca, Erciyes Üniversitesi Enerji Sistemleri Mühendisliği bölümünde okutulan Enerji Ekonomisi ve Politikası dersini alan öğrenciler, dersi aldıktan sonra bir teste tabi tutulmuştur. Bu testin içeriğinde, teorik soruların yanında oyun ile ilgili sorular da yer almaktadır. Testte, öğrencilerin genel başarı oranı %76,78'dir. Simülasyon oyunu ile ilgili sorulardaki başarı oranı ise %98,0'tür. Test sonuçları da göstermektedir ki, simülasyon oyunu öğrenmede olumlu etki yapmaktadır. Simülasyon oyunu ileriki safhalarda geliştirilerek elektrik piyasaları ile ilgili akademik çalışmalarda da kullanılacaktır.

Anahtar Kelimeler: Elektrik piyasaları, Simülasyon, Oyun ile öğrenme

ELECTRICITY MARKETS SIMULATION GAME

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Erciyes University, Graduate School of Natural and Applied Sciences

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Supervisor: Asst. Prof. Saltuk Buğra SELÇUKLU

ABSTRACT

In the previous century, electricity trading was monopolized and controlled by the government from its generation, transmission, and finally, to its distribution to the consumers. This regulated system does not offer consumers the option to select their utility services and therefore consumers are obliged to the price that is imposed on them by the authorities. With the inception of the deregulation of the electricity sector at the end of the 20th century, independent electricity generation companies joined the market. Thus, a competition was introduced resulting in cheaper prices and better-quality services for the customers.

The deregulated electricity market, however, poses challenges to new students and professionals because of its innate complex and evolving nature. To help solve this problem, a web-based simulation platform was developed as a game using web programming languages such as PHP and JavaScript in this study.

After students played the game, a questionnaire was issued out to test their level of understanding of the deregulated electricity market. It was shown that the students' comprehension after using the simulation game increased by about 95% proving that simulation games simplify intricate concepts because of the pragmatic environment they provide to the users.

Also, students taking the Energy Economics and Policy course taught in the Energy Systems Engineering Department of Erciyes University were subjected to a test after taking the course. The content of this test includes questions about the game along with theoretical questions. In the test, the overall success rate of students is 76.78%. The success rate in questions related to the simulation game is 98.0%. The test results also show that the simulation game has a positive effect on learning. The simulation game will be developed in later stages and will be used in academic studies related to the electricity markets.

Keywords: Electricity markets, Simulation, Game-based learning

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ABBREVIATIONS

API: Application Programming Interface

BETTA : British Electricity Trading and Transmission Arrangements

CSS : Cascading Style Sheets

EMG : Electricity Market Game

EUAS : Electricity Generation Company

EPDK: Energy Market Regulatory Authority

GW : Gigawatts

HTML : Hypertext Markup Language

ITEM-GAME : Investment and Trading in Electricity Markets Game

JDBC : Java Database Connectivity

JNI : Java Native Interface

JS : JavaScript

LEMM : Liberalized Electricity Market Microworld.

MABS : Multi-Agent-Based Simulation

MAS : Multi-Agent Systems

MW : Megawatts

NEPA : National Electric Power Authority

NERSA : The National Energy Regulator of South Africa

NETA : The New Electricity Trading Arrangements

PHP : Hypertext Preprocessor

SD : System Dynamics

SQL : Structured Query Language

TEAS : Turkish Electricity Generation and Transmission Company

TEDAS : Turkish Electricity Distribution Company

TEIAS : Turkish Electricity Transmission Company

TEK : Turkish Electricity Authority

TEMMAS : The Electricity Market Multi-Agent Simulator

TETAS : Turkish Electricity Trade and Contracting Corporation



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CHAPTER 1

INTRODUCTION

Electricity is traditionally generated by burning fossil fuels such as coal, oil, and natural gas but, recently, the inclusion of renewable energy sources such as solar, wind, and biofuels into the power grid have increased. The generated electricity is transmitted via high voltage transmission lines and distributed by low voltage distribution lines to the final consumer. The platform where electricity generators or suppliers meet demands from electricity consumers is referred to as the electricity market. It is a methodized platform for trading electricity [1].

Electrical power used to be controlled by the central government from its production to transmission to consumers [2]. From the late 1990s, myriads of institutional alterations in electricity trade were made in countries like the UK and Chile; and that quickly took over the whole of Europe and the United States of America [3]. The goals are to improve efficiency, moderate price, and encourage the involvement of novel investments as the competition is encouraged [3]. Larsen and Bunn [3] state that the changes in the electricity industry are country dependent, that is, each country adopted a particular approach at a specific rate of change.

1.1. Differences between the regulated and deregulated electricity market

Larsen and Bunn [3] presented some distinctions between the top-down regulated electricity market monitoring system and the deregulated and liberalized market. The move from a monopolistic and regulated electricity market system to the current deregulated and privatized system had not been a smooth and straight process. This caused numerous differences between the controlled and the competitive market. These differences can be summed up into two major levels: the industry and the company levels.

At the industry level, the changes that occur are further categorized into the corporate atmosphere, information, market power, and community research and development. Larsen and Bunn [3] stated that the corporate atmosphere remains largely steady with gradual changes in technology while demand and cost vary during the regulated period, but prices became volatile and unpredictable after deregulation. They also mentioned that information was provided to the public prior to deregulation but became unavailable after. Because the system is monopolized, market power was not a priority, but this changed after deregulation [3]. Public research and development are vital for future decisions but unreliable in post-deregulation as participating companies doubt the validity of community R&D [3]. Table 1 compares the regulated and deregulated electricity markets based on these characteristics.

Table 1. 1. Differences between regulated and deregulated electricity market at the industrial level [3]

Feature	Before deregulation (Monopolized)	After deregulation (competitive)
Corporate atmosphere	Largely steady with slow changes in technology. Demand and cost, however, vary.	Prices are unsteady and unpredictable;
Information	The public has access to information	Information is concealed.
Market power	Since it is monopolized, no problem is experienced.	Both market operators and companies take this seriously.
Public R & D	Civic R&D is used as a tool to plan for the long-term.	Companies are unable to justify the veracity of community R&D

At the company level, several factors are considered. These are company focus, management focus, customer focus, planning methods, and outsourcing. While the emphasis was on technicalities of the system in the pre-reformation era, this shifted to the most tolerable price in the post-reformation period [3]. Before the reformation, customers' needs are disregarded but they became the major stimulus to the competition

[3], which is an inherent characteristic of the deregulated electricity market. According to Larsen and Bunn [3], planning was successfully done in a top-down fashion by the government, but limited data adjusts to market highly uncertain after the deregulation. They also noted that while subcontracting is practically nonexistent at the time of regulation, it is continuously increasing after the reformation. Table 2 highlights these differences at the company level.

Table 1. 2. Differences between regulated and deregulated electricity market at the company level [3]

Feature	Before reform	After reform
Emphasis	Technicalities	Most acceptable price
Administration's focus	Technical	Commercial
Client focus	There is largely no concern for the customer	The competition allows for concern for the customer
Planning approaches	From the authority and implemented effectively	Evolving changes that encompass uncertainties and limited data.
Subcontracting	Almost nonexistent	Increasingly available

Paşaoğlu [4] stated that before the restructuring of the market, power plant investments used to be dependent on the optimization-based capacity expansion planning on the countrywide level. This planning was done to examine the generating quantity, the most efficient portfolio of supplying technologies, and the appropriate moment for investment and retiring of the plants to ascertain future customer bids and balance them at the minimum cost possible [5].

Regarding the aftermath of electricity market liberalization, Paşaoğlu [4] pointed out that electricity generation is no longer monopolized because the public authorities have left the market to take charge of its operations. The renewed role of the authorities has been planning or mapping out the market. Randomness and uncertainty are the major characteristics of the liberalized market owing to customers' requests and level of competition among suppliers which inhibit long term forecasting.

1.2. Electricity Market Reform

Erdogdu [6] presents a comprehensive review of the countries with advanced electricity market restructure and reasonable restructuring analyzing the dynamics of the electricity market restructuring and privatization of various countries, especially at the early stages. Below is the review of some countries and their course in electricity market liberalization.

1.3. Advanced Countries in Electricity Market Restructuring

Regarded as the paragon of the electricity market reform, the UK is one of the earliest countries which has implemented successful electricity market restructuring that the World Bank advises other countries like Ukraine, Brazil, and India to emulate [6]. Erdogdu [6] stated that it is the same British style that instigated the European Union's regulation and starting from 1990, the UK's vertically fused government-owned power utility, Central Electricity Generating Board (CEGB), was modernized to differentiate the state grid company from the generation companies: PowerGen, Nuclear Electric, and National Power. Except for Nuclear Electric, which Newbery and Pollitt [7] reported having been sold as British Energy in 1996, the remaining of the companies were privatized. According to Littlechild's review [8], the new arrangements had proved entirely feasible.

Just before the privatization, a dozen regionally-based electricity companies (RECs) took over the responsibilities of the 12 area boards, thus making the National Grid Company charged with transmission [9]. Concurrently, the compulsory pool systems were established in 1990, 2001, and 2003. The New Electricity Trading Arrangements (NETA) and the British Electricity Trading and Transmission Arrangements (BETTA) executed different reforms respectively hence restructuring, regulation, privatization, and competition, which are the features of electricity reform, were encompassed in the British system thus giving power to every customer to select their supplier as the system is fully liberalized [6]. Thomas [10] concluded that prices have reduced about a quarter and the system's reliability is increased.

Erdogdu [6] reported that in implementing reforms in the power sector in 1982, Chile was the first country to begin the reform process in the electricity sector. Together with Argentina, they made the most unconventional and deep-seated reforms of the sector [11]. Since the passage of the power law, leading to the creation of the wholesale

market in 1982, Chile's electricity sector was made private except the transmission structures which made companies such as Endesa group fairly monopolized [6]. With a high share in the fourth quartile of the transmission network, Endesa supplied 80% of Chilean electricity and hold a market share of just below 50% as a distributor [12].

Erdogdu [6] recorded the existence of 31 electricity producers, 5 transmission firms with 36 companies doing the distribution but only a few are controlled. Nagayama and Kashiwagi [13] explain that it was due to the openness and lack of constraints of the sector that allowed many foreign companies to invest in the electricity sector.

Owing to the fact that some electricity producers having an oligopolistic market share, allowing the possession of transmission companies by some generation companies at the time pool market-style was introduced, embracing competition and cutting down the market power owned by some companies became an issue [6].

Idolized as one of the most triumphant in its reform, Argentina succeeded in reducing losses in the power system while enhancing the quality of electricity generation [14]. Argentina's success was due to lessons drawn from other reforms such as that of the UK [6].

1.4. Countries with constrained reforms

Countries such as Turkey, the United States of America (USA), New Zealand, and Australia have not fully employed the liberalization of the electricity sector as it is done in the UK and Chile [6]. Turkey and the USA are discussed as examples here.

Turkey is one of the countries which could not begin the process of electricity trading restructuring earlier. The Turkish power industry used to be controlled by the Turkish Electricity Authority (TEK: Turkiye Elektrik Kurumu), which is a state-owned top-down integrated corporation [6]. In 1982, the private sector was reformed so that private firms can own power plants and supply electricity to TEK [6]. In 1993, TEK is separated into two companies, the Turkish Electricity Generation and Transmission Corporation (TEAS) for generation and transmission, and the Turkish Electricity Distribution Corporation (TEDAS) for distribution [6]. Later, as noted by [15-17], TEIAS, a transmission company, EUAS, a generation company, and TETAS, a wholesale company replaced TEAS. TEDAS had possession of more than 90% of the

distribution network with 21 branches and went into a privatization program [6]. The reformation of the Turkish electricity system is illustrated in Figure 1.

The managerial role of government-owned power plants is assigned to EUAS [6]. From the analysis done by Hebasli [18], while, admittedly, adjustments in estimates might occur, EUAS owned more than half of the anticipated 41 GW total installed volume by 2009, the majority of which would be generated from hydro sources. Bagdadioglu and Odyakmaz [19] noted that, in 2006, of all the power plants operating in Turkey, EUAS controlled 48%. To establish fairness in the cost arrangements, EUAS was further subdivided to oversee hydroelectric, lignite, and gas-fired plants [19]. Whereas EUAS retains control of main hydropower plants to offset isolated expenses, thermal and minor hydro plants were privatized [19].

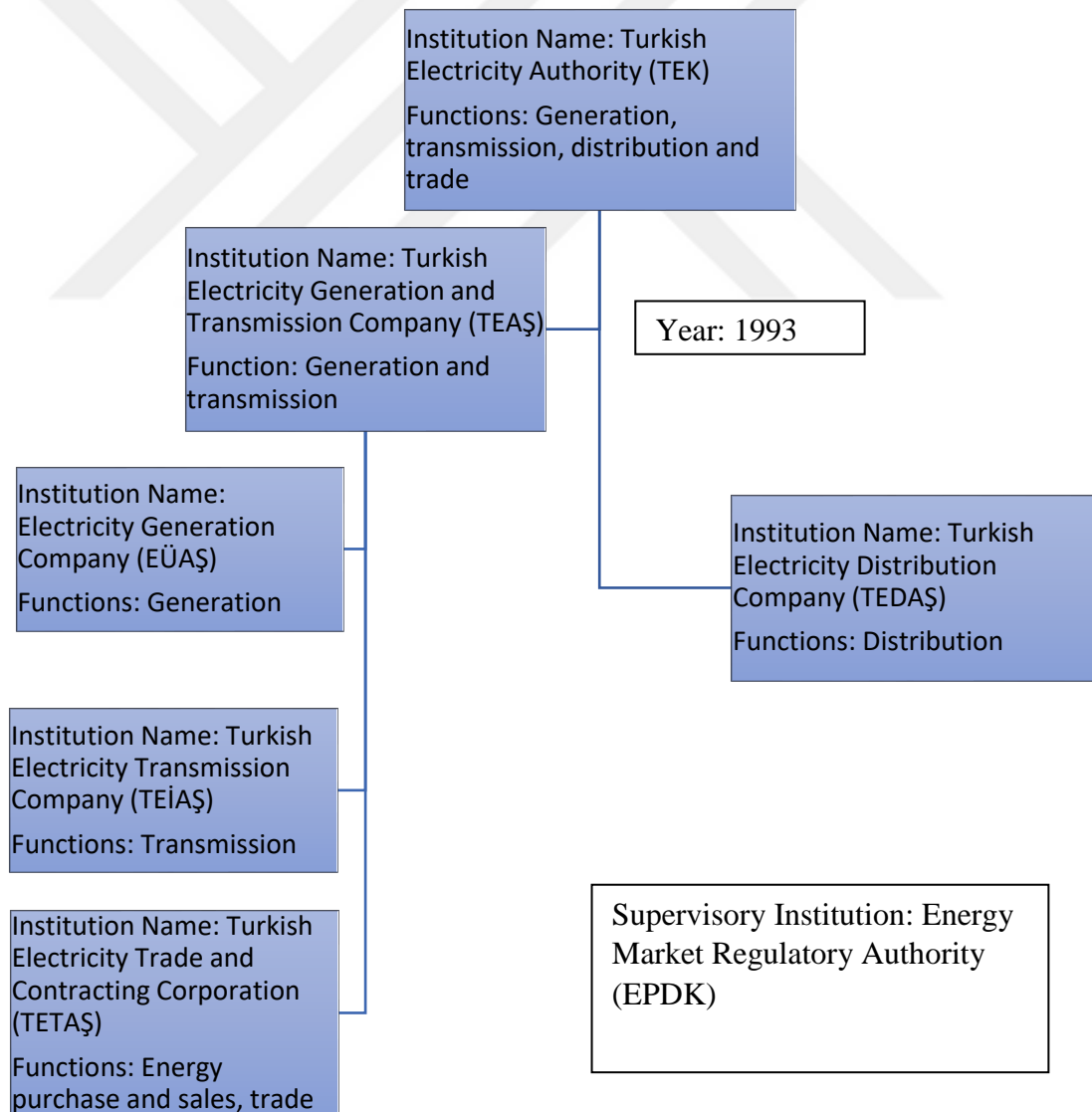


Figure 1. 1. The reformation of the electricity system in Turkey

Due to the USA's history of having a largely regulated electricity sector [6], it could have contributed to the US not to entirely adopt liberalization [20]. The nascent of efforts to change the electricity industry in the USA was in the 1970s and the electricity sector was characterized by market-focused action and weak supervision [6]. About half of the states have liberalized the sector by the year 2008 [21]. As argued by White et al. [22], there are averagely striking disparities in electricity prices throughout the states, and consumers and novel producers in some states were given incentives to motivate the reforms for competition and price decrease. They assert that these incentives are only limited to the states with high electricity prices to launch reforms. According to Joskow [23], the electricity price disparity is the reason some states introduced the electricity sector remake whilst some did not. Also, at the beginning of the 20th century until 1970, as noticed by Joskow [24], the electricity prices declined sharply. However, they rose acutely from the mid-70s to mid-80s which is a result of an increase in primary energy cost, high-interest rates, constrained environmental requirements, and the purchase of aggressively expensive nuclear plants. Sioshansi [25] maintains that the prices began to decrease from the mid-1980s to 1990 because of the fall in input prices, but prices in some states continue to be above average. Sioshansi [25] reasons that the lingering of high prices acted as a catalyst to the restructuring of many states. Before the enforcement of the reformation in the US, the mean price of electricity in 1997 was about 7 cents/kWh. It is 8.4 cents/kWh and 4.5 cents/kWh for residential and industrial, respectively. While these prices are low for advanced countries [4], the Northeast states and California recorded averagely higher prices compared to the remaining country which led to their restructuring in 1996 and 1997 [25]. It was confirmed by White et al. [22] that the states with higher prices started the reforms thus clarifying the model of electricity restructuring in the US.

As indicated by Sioshansi [25], the previous low growth rate in retail competition led to the failure of countrywide electricity market competition. He mentions the unsuccessful California market, inconsistent outcomes in some states which launched the retail competition, unanticipated challenges in some wholesale markets, and failure on the part of congress to promote competition to the national stage.

As an addition to the reasons above, the reform in California had vowed to produce dependable service at a cheap price. The electricity restructuring was launched in 1998. Before the reform, the electricity generation was redundant, and the prices were high.

While the national average prices for residential and industrial electricity were 8.43 cents/kWh and 4.53 cents/kWh, respectively, residential electricity was 11.05 cents/kWh and industrial electricity is 6.77 cents/kWh in California [24].

Joskow [24] states that electricity cost was a problem at the beginning of the 1990s such that the state's economy worsened because of the recession. Due to the insistence from industrial consumers to lower the price and private power generators to widen the chances to expand the market for their electricity and introduce restructuring, California was the pioneer in electricity reform [6]. The novel reform establishment consists of power exchange, reconstruction, stabilizing consumer prices in 1996, and forbid future semi-permanent electricity purchase arrangements [6]. Even though state-owned companies were precluded in the liberalization process, they must maintain their supply of electricity at a low price [6].

From mid-1998 to 2000, even though wholesale prices were considerably high, the market was typically satisfactory [6]. Erdogdu [6] stated that the cost of electricity began to increase in the late spring of 2000 and the earliest planned electricity power outage was experienced in the middle of 2000. At this time, three main companies began to lose heavily and could not pay their debts. The electricity-producing companies were unwilling to trade on the power exchange because their contracts were not respected. In addition to the limit on consumer prices which made it impossible for wholesale prices to translate into high electricity costs for consumers which could have resulted in low consumption, the ban on long-term contracts caused the inability to employ tactics to eliminate financial risks. Consequently, the exchange collapsed and was financially ruined in March 2001 [26].

The inability of supply to meet demand in the summer months of 2000 because of the sharp rise in demand, considerable low supply of hydropower because of warm weather, the astronomical increase in the cost of natural gas resulting in high marginal cost and lack of financial resources were the primary causes of California's trouble [27]. Even though the issues in California stalled the reformation nationwide, most states were devoted to the implementation of the electricity market liberalization process [6].

1.5. Countries with little or no reforms

The reformation process saw little implementation in Africa therefore it is difficult to do country by country analysis. The major effort was to promote foreign individual

investments in the electricity sector, but some countries tried the electricity industry restructuring [6]. Before 1994, during the apartheid era in South Africa, the policies were such that only the white residents profited [6]. Erdogdu [6] states that electricity policies consisting of power supply target adequate electricity production to industries in the chemical, agriculture, and mining which serves as the anchor to their economy. He noticed that the establishment of democracy in 1994 enabled a change in policy and the launch of the National Electricity Regulator in 1995 which replaced the Electricity Control Board that was in operation since 1987. He maintains that Eskom, a property of the government, controls the electricity industry from its generation to transmission thereby holding a monopoly status in electricity production and transmission. Eskom was made a public company pursuant to the Eskom conversion Act of 2001. The National Energy Regulator of South Africa (NERSA) regulates Eskom in conformity with the Electricity Regulation Act of 2006 [6]. However, as noticed by Newbery [28], the electricity sector restructuring in South Africa is negligible as demand outweighs supply, the regulator is established but prices depend on previous prices, and individual investment was disregarded. Eskom still produces about 95% of the nation's electricity [6].

Commercialized in 1988, NEPA, the Nigerian government-owned electricity utility's monopoly loosened, and the competition framework was introduced [6]. Currently split into 18 companies, NEPA consists of 1 transmission 6 generation, and 11 distribution companies [6]. The afterthought is that the companies would be privatized [29].

1.6. Electricity market simulation games

Electricity trading has been implemented as a simulation software using disparate approaches and in diverse environments. Some of these tools use only humans as agents or the players who represent generation companies as in real life, others use computer-simulated agents while some combine the two approaches. This section explores some of the literature which executed some of these simulation tools.

Trigo et al. [2] developed a simulation tool for electricity trading. Labeled as ITEM-game (Investment and Trading in Electricity Markets), it employs both humans and computer-simulated agents that compete against each other as generation companies. The predecessor of this game, TEMMAS (The Electricity Market Multi-Agent Simulator), also a simulation tool, independently reinforces the learning approach to

determining the most suitable bidding plan during trading [30]. ITEM-game, though derived from TEMMAS, is more human dependent.

Built as a multi-agent-based simulation (MABS) and characterized by two distinctive environments, TEMMAS incorporates 1) environmental platform which possesses features like power generators and 2) unique surroundings like bid price and consumer demands that quantify such environments in 1 [30].

Lam et al. [31] who developed their simulator in the Java programming language to demonstrate its benefits also explore the electricity market. They refer to Java as a network-focused language, which is capable of running on any platform (Windows, Linux, macOS, etc.) because of its inherent feature called Java Virtual Machine which allows Java programs to be distributed across all platforms. They also defined “agent” in “multi-agent systems” (MAS) as a software agent that achieves a goal as allowed by the software programmer. The simulator consists of a platform 1) for the agents to interact with, 2) to execute market mechanisms, 3) to host data such as bids (database), and 4) to compute market results such as the market price. To achieve participation among the agents, JATLite (Java Agent Template, Lite), a MAS framework, is implemented and JDBC (Java Database Connectivity), which is an Application Programming Interface (API) is used to connect the program to the database. They use Java Native Interface (JNI) for the computations because of its ability to interface with tools like MATLAB’s Power System Toolbox and also take advantage of some optimization software. The computed results are then returned to the participants.

Similar to [31], Liu et al. [32] also develop a simulation software using Java with JATLite and JNI but incorporate features of MATLAB. Here an information tool called the OASIS is used for interaction between the agents.

Using java for agents’ communications, MATLAB for calculating the market price, and a tool known as Tcl (Tool Command Language) to connect MATLAB to Java, Contreras et al. [33] present another power trading tool. The Java program is integrated with applets that use web browsers for their implementation. The Tcl, one of C programming language’s library, is used to control the interaction between Java and MATLAB. The choice of MATLAB was due to its simplicity with matrix operations.

Converting the system dynamics (SD) model, Paşaoğlu [4] created the Liberalized Electricity Market Microworld (LEMM). The SD model monitors changes in systems in varying circumstances. Developed using Stella 7.01R, the SD model can track the

factors that influence supply and demand, and hence the market price. Present in LEMM, microworld is defined as a pedagogic environment that, on the implementation of a model, depicts the real world [34]. Paşaoğlu's model depends on four components namely the accounting, request, fiscal matters, and capacity development components. Built by Davis [35], the energy market game is being used to aid students and other stakeholders increase their knowledge of the liberalized market. The web-based game was implemented essentially using Python and R. It is hosted on apache (a web server tool), and the energy market game profited from Python modules such as scipy, pandas, and selenium to expedite development. Other modules such as dplyr, ggplot2, and linprog from R were also used.

1.7. Aim and importance of the thesis

Despite the introductory courses concentrating on the workings of the electricity markets at colleges, college students find it difficult to fully comprehend the concepts and the strategies that are employed in electricity trading because of the multidisciplinary and complex nature of the electricity market [4].

The development of simulation games has become ubiquitous recently because of the enormous advantages they provide. Games simplify the complexity of the real-world systems in a rather pragmatic way. The general objective of games is to practically explain the rather sophisticated electricity market scenario to students and young professionals.

Learning has been a great challenge and the best method can be subjective. The main importance of this thesis is the learning method employed in its analysis of the energy market system which has been unanimously endorsed and supported by many researchers.

Even though research games have been proven to be vital, it does, however, depend on the field of study. In their review, Randel et al. [36] compared the success of games and normal classroom lessons and their effects on the subject area. After examining 67 articles, 38 of them (57%) scored both game and the classroom lesson equally. 22 articles (33%) undoubtedly rated games higher and five (7%) found games unsatisfactory. The remaining two articles (3%) conclusively validate classroom lessons. With regards to which subject area is more explanatory with simulation games,

mathematics proved to be the best as 33 out of 46 (72%) preferred games and the social science simulation games showed no difference when compared with the regular classroom sessions.

Jennings [37] compared three learning methods: case-based learning, simulation method, and action learning, and the participants rated the simulation method as superior to the action learning and case-based learning methods. Moreover, Senge [38] stated that human beings learn best through personal experience, particularly when feedback from actions is rapid and unambiguous.

Ligtvoet and Chappin [39] are more pragmatic in their analysis when they examine students' reactions during a typical electricity market simulation game. To avoid politically accurate responses, the process was not mandatory. A total of 53 students were issued with a questionnaire out of which only 32 responded to all the questions. Students were made to respond to the questions while they play many rounds of the game. Concepts such as the bidding process, market power, factors that affect the prices, and consequence of policies are monitored. Generally, it was determined that student's comprehension of the major ideas (bidding process, market power, factors that affect the prices, and consequence of policies) being tested, improved throughout the game as the game demonstrates them. After the last period, only about 15% of the students could not fully grasp all the concepts but they all understood the bidding process. They claimed that the first round saw the students spent about 4 hours to organize their bids in an overrated way. In the same manner, these numbers reduced to 2 hours and just below an hour in the seventh and eighteenth periods respectively. Comparatively, the bidding process was well understood than other concepts, which alludes to the fact that it was well explained in the class but other concepts such as a consequence of policies that are innately complicated and could only be best observed during the game [37]. Figure 2 shows their graphed outcome in rounds (period) 1, 7, and 18.

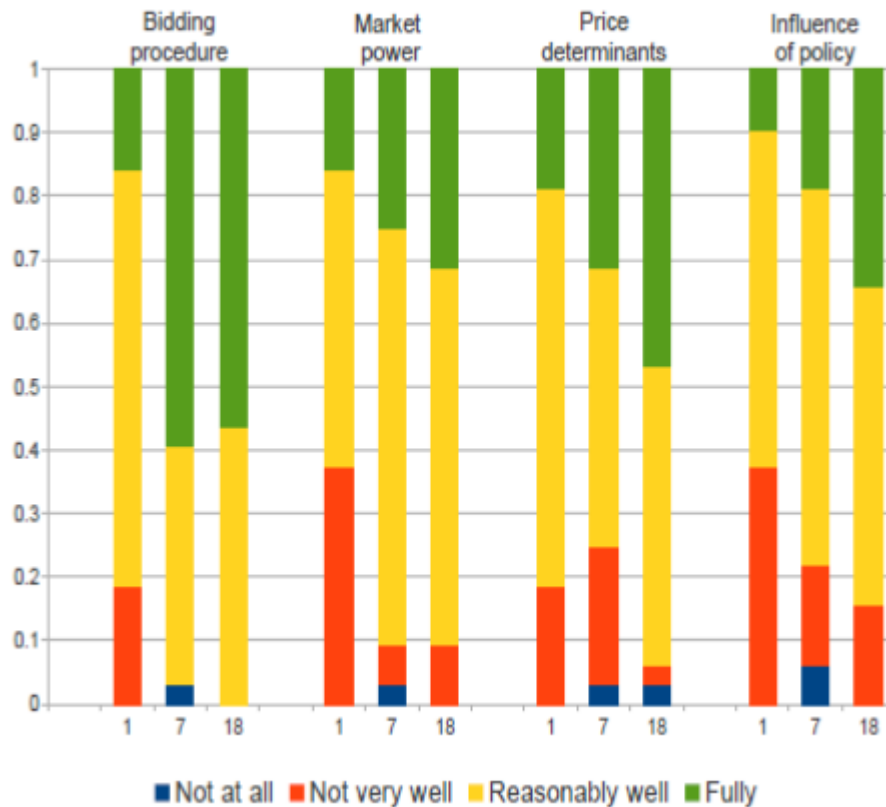


Figure 1. 2. Students comprehension of key concepts in Electricity trading [39]

The main aim and contribution of this thesis is to provide a learning tool for electricity markets. As the major purpose is to get students to understand the mechanism of electricity trading in a practical sense and the study method this work engages, it is overwhelmingly satisfying on seeing the support from the literature on the study method.

The future goal of the study, on the other hand, is to use the simulation game in academic studies related to the electricity markets after developing and modifying it. The purpose is to observe player behaviors so that artificial intelligent agents can be designed for future research. We are still working on analyzing data for this purpose and the game will be modified accordingly.

After the game is modified to include AI-agents, several scenarios will be examined for electricity markets, such as different market mechanisms and designs, carbon trade designs, renewable portfolio standards and their effects on the market, and demand-side management.

CHAPTER 2

METHODOLOGY

The developed Electricity Market Game (EMG) is web-based with platforms for (1) player interaction, (2) the power exchange, and (3) the database. A website (theemgame.com) is used for the interaction and it consists of a front-end and a back-end. Each end requires specific development techniques to achieve the desired goals. The front-end consists of the visual aspect which provides the user the ability to interact with the website, the back-end, on the other hand, represents the operations that do not involve the user, like market clearing and the computation of the market price. The front-end languages include HTML (Hypertext Markup Language), CSS (Cascading Style Sheets), and JavaScript, and the back-end languages are PHP (Hypertext Preprocessor) and SQL (Structured Query Language).

HTML is the language that is central to the webpage. It forms the framework of the website on which anything else can be built. It is fundamental to web development. It controls how content on a webpage is displaced and it communicates with web browsers via web servers.

CSS works with HTML to give the web page an esthetic look and modifies some attributes of HTML elements.

In terms of functionality of the webpage and the interactions, JavaScript (JS) plays a major role. With the assistance of JavaScript, a player can select a plant, make, or delete investment, choose, and make a bidding plan.

PHP (Hypertext Preprocessor) is essentially used to exchange data with the database. It sends the bid data to the database and reads the market results from the power exchange to be displayed on the webpage. The following sections detail the architectural arrangement of the EMG.

2.1. Player Interaction Platform

This component is developed using PHP, JavaScript, and other web development tools like HTML and CSS. This is further divided into the manager and agent platforms.

The manager dashboard is where the manager selects registered players and consequently creates a game. The manager acts as an independent system operator and oversees the smooth running of a game session. The manager can activate the power exchange which calculates the pool price.

The players, each representing a generation company, can join the game through the agent platform. This platform is mainly made up of the company information, strategy, and market outcome pages. Each player aims to make the most profit possible.

The players' first point of contact after logging in the system is the company information page where brief information about the game is presented. They can then move to the strategy page. This page is split into two parts, namely investment and trading.

At the top right corner of the investment section, there is a green box containing vital information about the game including the company name, the period in which the game is being played, the company's budget at that period, and expected electricity demand in megawatts (MW) for that period (Figure 3).

Period	5
Company Name	kiki
Budget(US\$)	822,890,623.61
Demand(MW)	2246.65

Figure 2. 1. A player's information in period 5

In the middle of the page below the period information is a dropdown menu (Figure 4). This contains all the available investment options (power plants) in the game. Details about each power plant are displayed in a table below the drop-down menu. A player can only buy a power plant if the company has enough budget. Each power plant and its

corresponding properties such as price, capacity, and the construction period are shown in Figure 5.

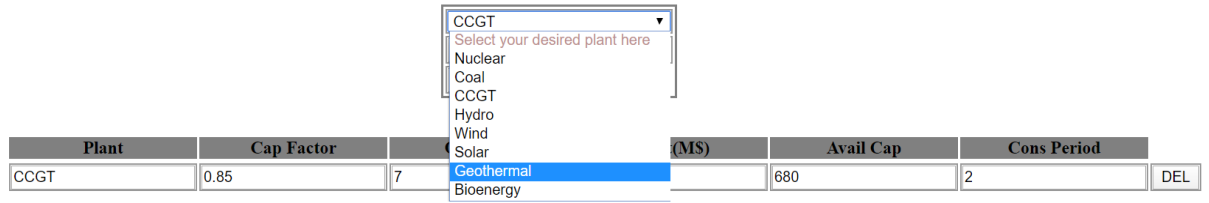


Figure 2. 2. A drop-down menu showing available power plants for investment.









Plant	Nuclear	Coal	CCGT	Hydro	Wind	Solar	Geothermal	Bioenergy
								
Price(MS)	800	170	70	60	30	40	60	30
Capacity(MW)	900	600	800	120	30	30	50	20
Efficiency/ Cap factors(renewables)(%)	30	40	60	35	30	16	75	85
CO2_Emission(ton/MWh)	0.0	1.0	0.4	0.0	0.0	0.0	0.0	0.2
Con. Period	5	4	2	2	2	1	2	2
Op Period	10	9	7	9	7	6	8	6

Figure 2. 3. Properties of each power plant

To the right of the trading section, there are two different tables for portfolio and construction (Figures 6 and 7). The portfolio table shows power plants where players can bid with their respective properties such as their available quantities and operation and offline periods. Plants under construction table contain similar information as those in the portfolio table. It has additionally an “online in period” column which is the period in which the acquired plant would be available. The construction table informs about all newly purchased power plants until their construction period is completed.

Your portfolio				
Plant Number	Technology	Available Quantity (MW)	Operation Period	Offline In Period
1	Hydro	60	5	10
2	CCGT	680	3	8
8	Hydro	60	8	13
3	Coal	510	9	14
9	CCGT	680	7	12
Total: 1990				

Figure 2. 4. A display of portfolio table

Plants under Construction				
Plant Number	Technology	Available Quantity (MW)	Construction Period	Online In Period
10	Coal	510	3	5
11	Bioenergy	17	1	3

Figure 2. 5. A display of construction table

Just below the “Trading” title is a drop-down menu to the left and followed by three input boxes to the right (see Figure 8). This is where bidding is done. To bid, a player must first select a plant number. These are the plant numbers from the portfolio table. On the selection of a plant number, its corresponding quantity is automatically displayed in the adjacent box. The player can now enter how much quantity out of the displayed quantity and the price in the last box. Finally, the “Add” button is clicked to append the bid to the bid table below.

After all, bids are added to the table, the player can submit all bids and investments.

The screenshot shows a web interface for bidding. On the left, there is a dropdown menu labeled "Select Plant Number" with a list of plant numbers: 1, 2, 8, 3, and 9. To the right of the dropdown are three input fields: "Available bid", "Bid quantity", and "Bid Price". An "Add" button is located to the right of the "Bid Price" field.

Figure 2. 6. The bidding environment

The results of the bidding process are displayed on the market outcome page (Figure 9). These include how much of the player’s bids are accepted, which plants are traded, their profits or losses, fuel prices, carbon emissions, and the market price of the game period. Also, the rankings of all players are displayed according to their budgets.

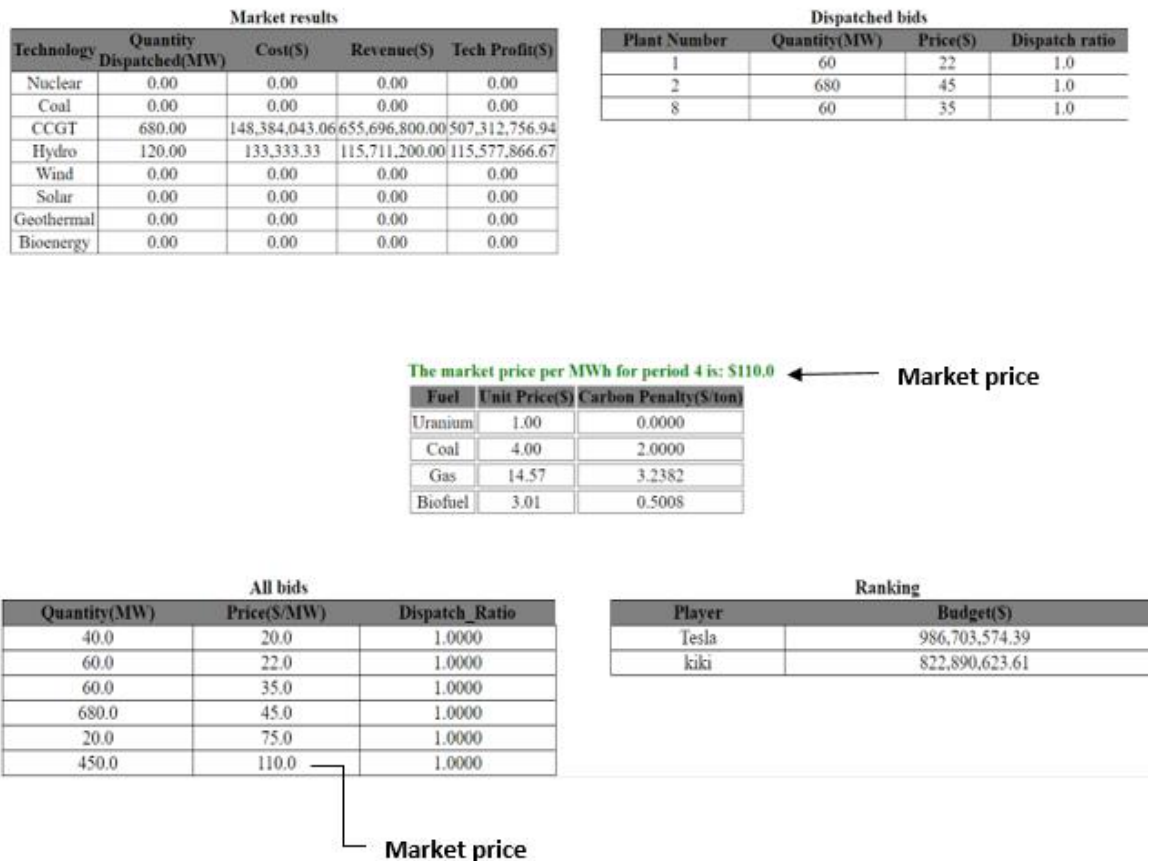


Figure 2. 7. Display of market results

There exists also a summary page which is a graphical representation of the results (Figure 10). This considers all the results of all the periods, that is, the market prices, demands, and fuel costs for each period.

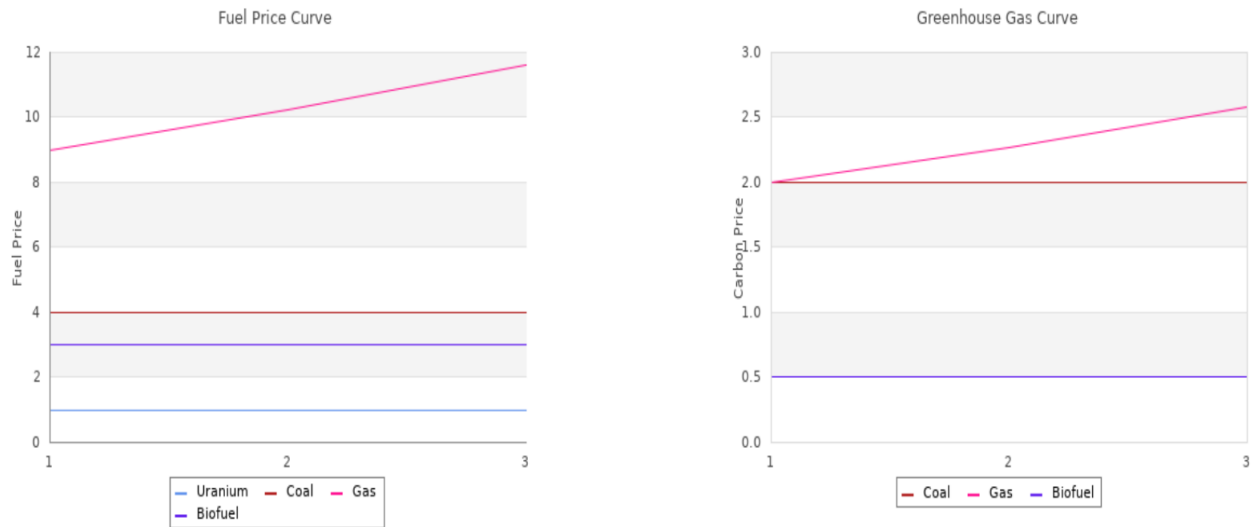


Figure 2. 8. Fuel price and carbon emission graphs

2.2. Database

SQL language and MySQL database are used for data management. The database serves as an intermediary or a bridge between the agents' bid data and the power exchange.

2.3. Power exchange

This module is purely developed with PHP. Even though quite challenging, as PHP does not make it easy to work with matrices as other languages like MATLAB, it simplifies connecting to the MySQL database operations.

The power exchange contains an algorithm that calculates the market price. The results are then sent to the database and the players' webpages. Figure 11 represents the structure of the EMG.

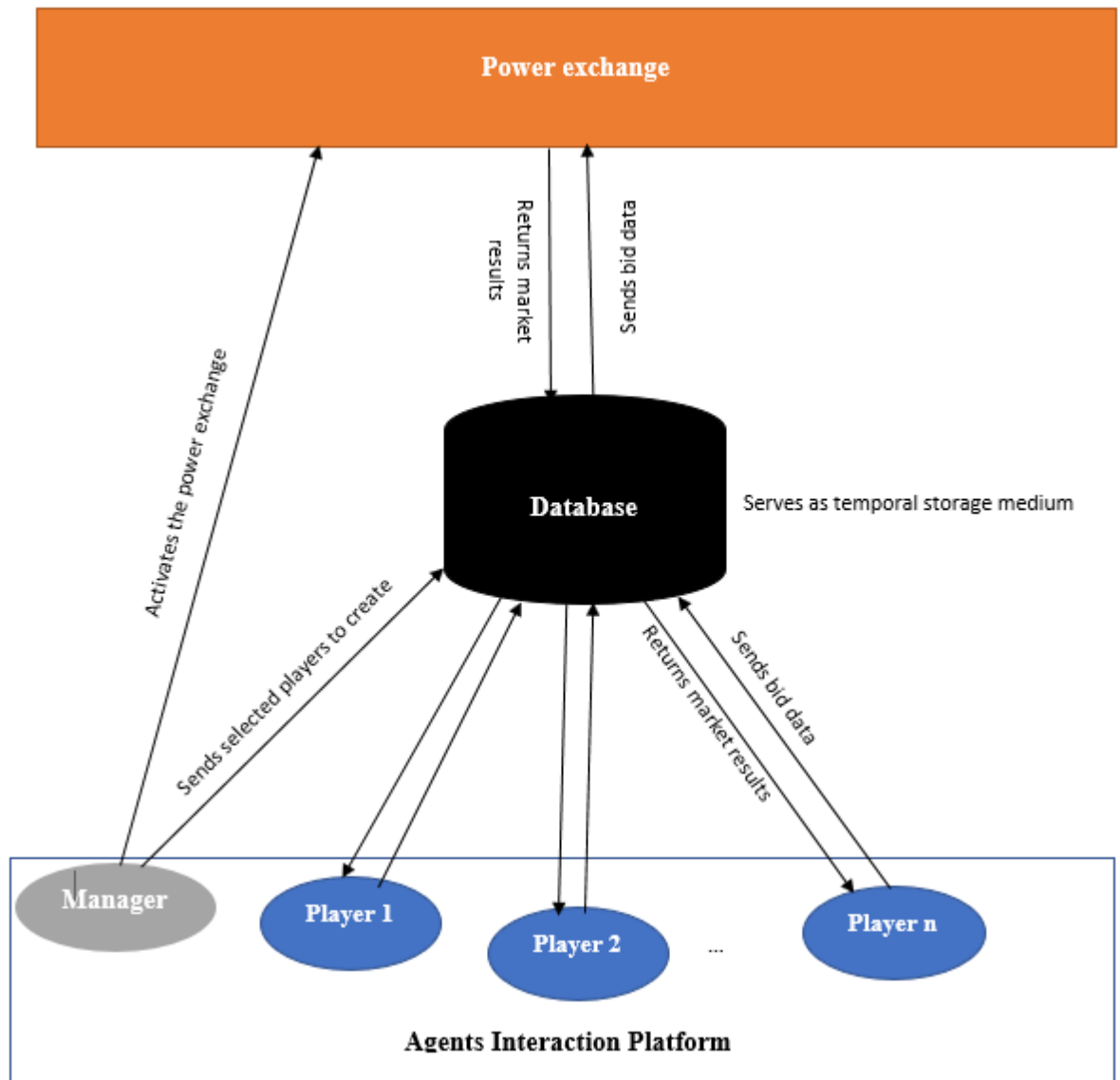


Figure 2. 9. The structure of the EMG

2.3. Determination of the market price

The bids sent by the players are collected, aggregated, and sorted in ascending order with respect to the bid prices. Each quantity and price pair is accepted until supply meets electricity demand. The dispatched ratio of each accepted bid is also recorded. The price at which supply meets demand is the market price. These are illustrated in Figures 31 and 32.

Details on each component such as investment and bidding processes and market price determination are demonstrated in Chapter 3.

CHAPTER 3

GAME MANUAL

The major roles in the game are played by the manager, who supervises the setting-up of the game, and the player whose key functions include investment in power plants and trading them for profit. This chapter gives detailed information about how to set up and play the game.

3.1. The manager

The manager role is selected as demonstrated in Figure 12. This ensures that the user registers and logs in with expected details.

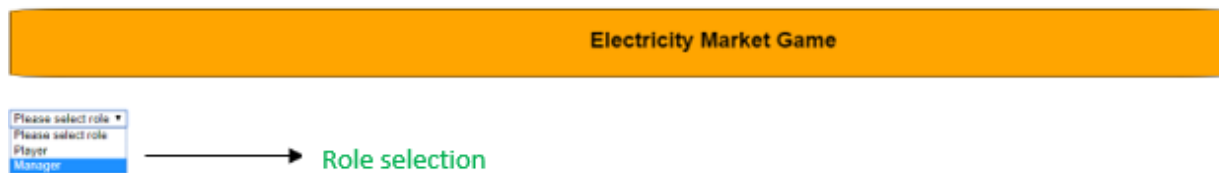


Figure 3. 1. Role selection

Managers need to first register by clicking the register link which leads them to the registration page (see Figure 13).

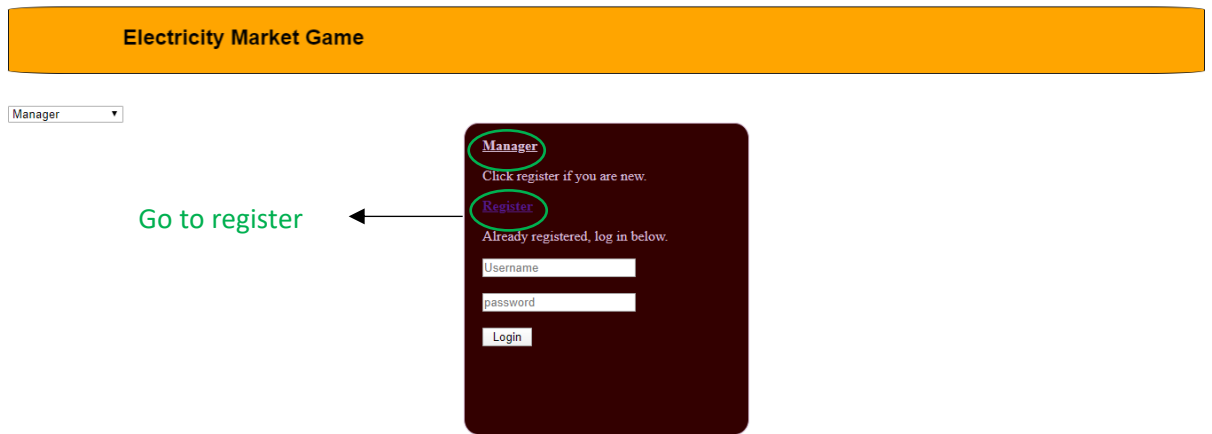


Figure 3. 2. Log-in interface

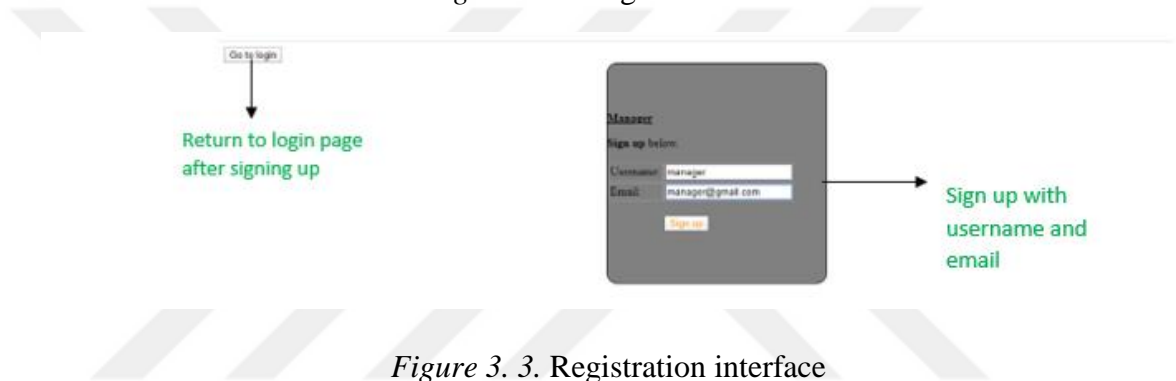


Figure 3. 3. Registration interface

In Figure 14, players input their registration details. The username will be the company name during the game and the email is used to send automatically generated passwords. The password is also displayed in an alert box as in Figure 15.

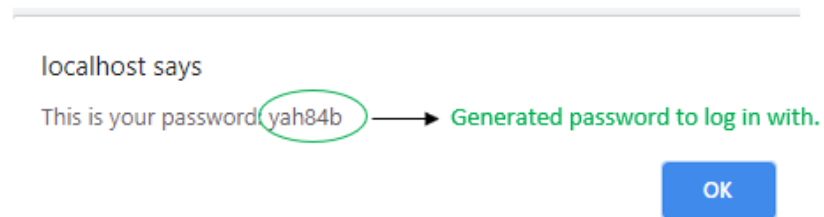


Figure 3. 4. Generated password alert box after registration

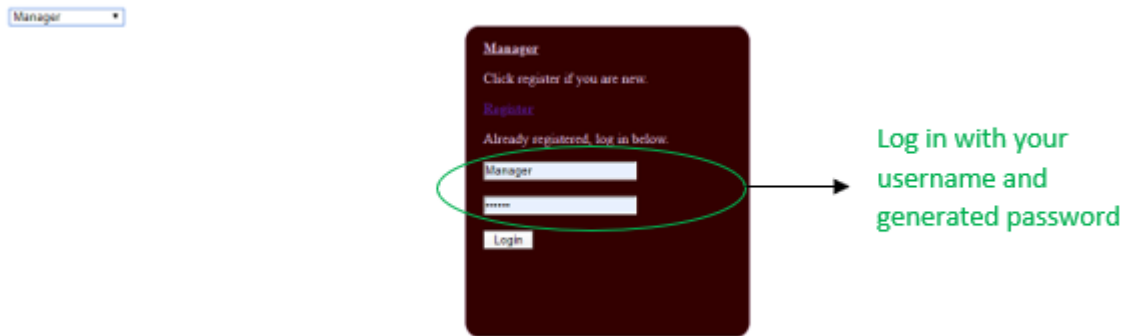


Figure 3. 5. Manager logging in with username and password

After registration, the manager returns to the login page, selects the manager option, and, with the data provided, logs into the dashboard.

At the dashboard, as shown in Figure 17, the manager’s duties are enumerated. First, the manager must click the “Delete game” button to clear previous game data and to pave way for the new game that would be played. Subsequently, in Figure 18, the name of the new game is provided, players are selected, and the game is created.

The manager can select the players only after they have registered in the system. Player names would be presented at the manager’s dashboard after their registration.

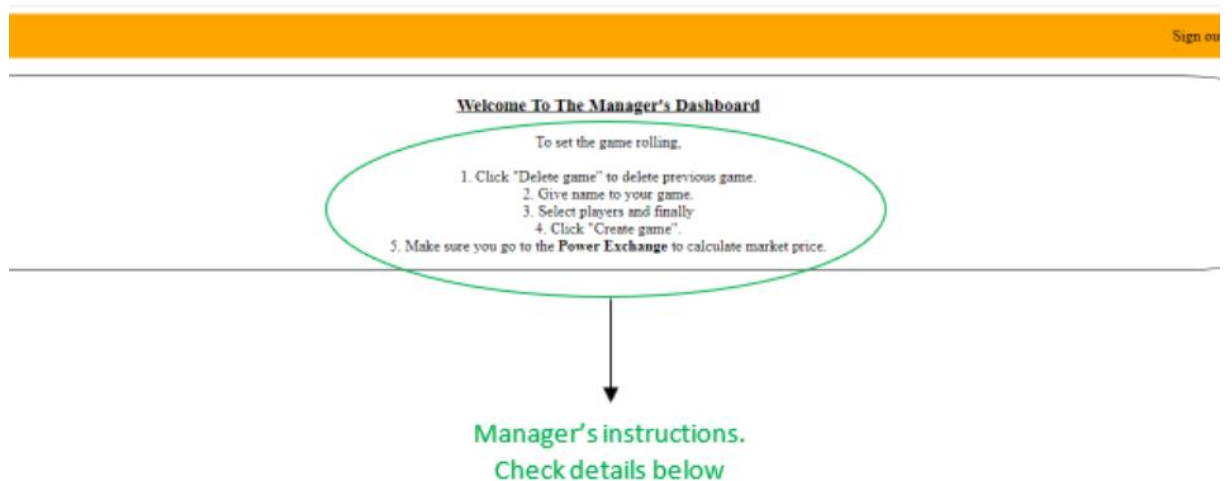


Figure 3. 6. Steps to be taken by the manager

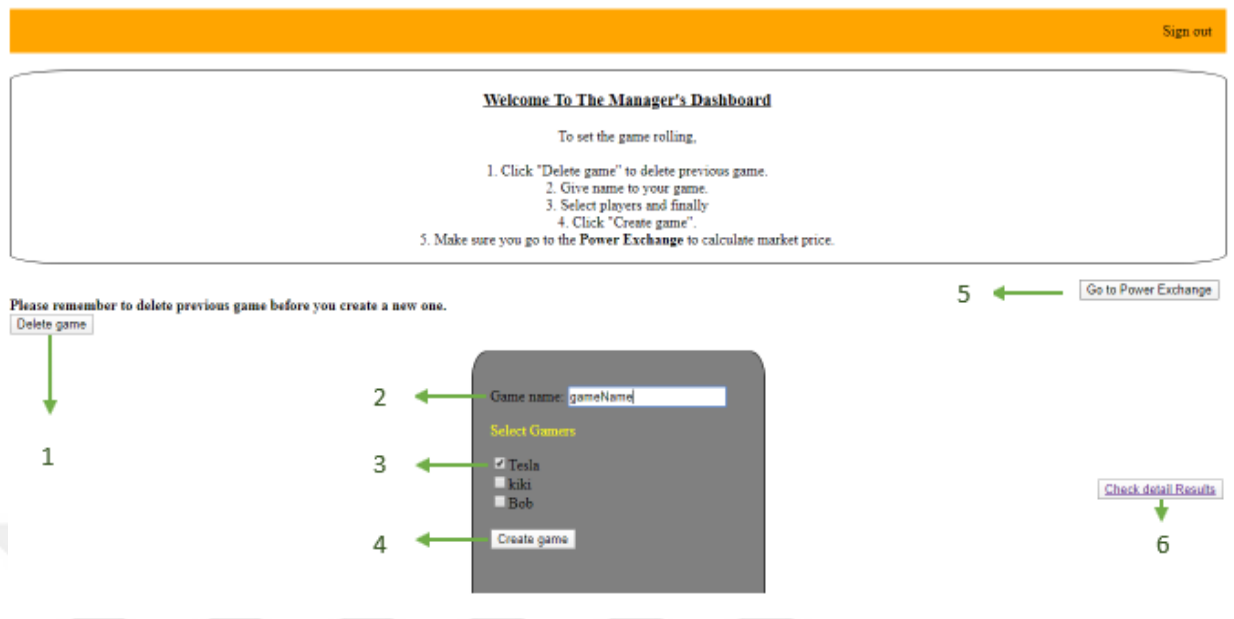


Figure 3. 7. Details of the manager's duty

After the game creation, to enable the computation of the market price from bids that would be sent by the players, the manager must click the “Go to the Power Exchange” button at the top right corner (see label 5 in Figure 18). The power exchange illustrated in Figure 19 consists of a timer and a box in which the market price is shown along with the demand for the next period. The timer allows an interval for the players to prepare and send their bids before the calculation is done.

The manager can check results for each previously played game during and after the game by clicking label 6 in Figure 18 which directs the user to Figure 20.

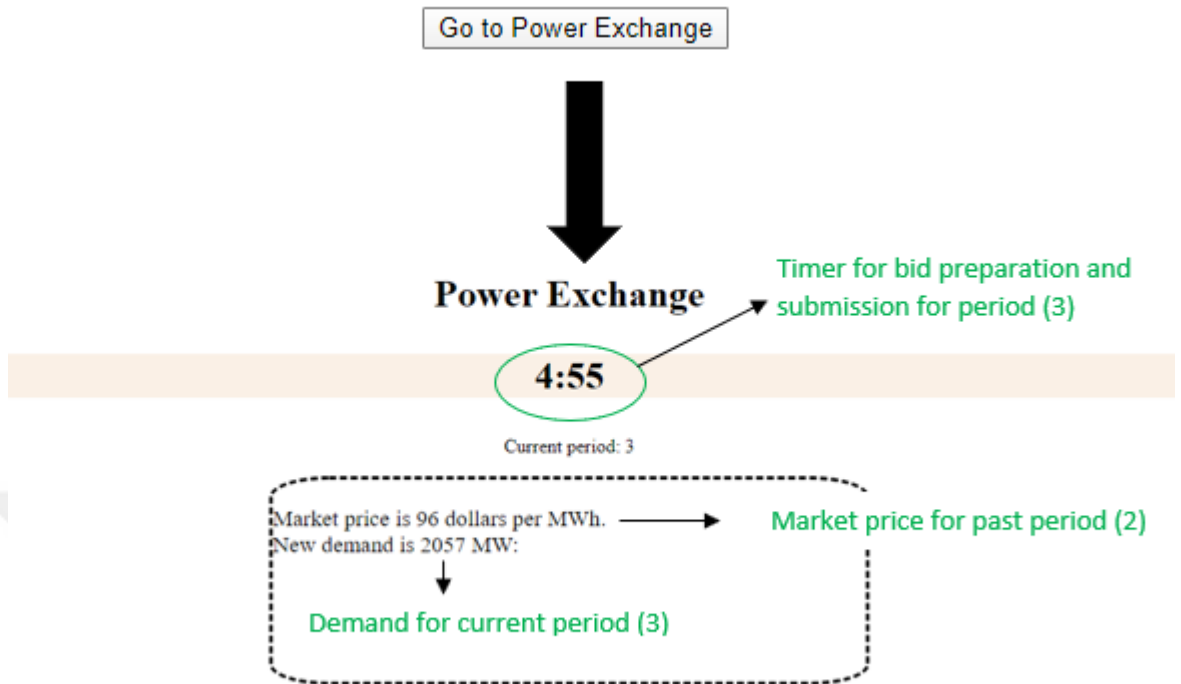


Figure 3. 8. The power exchange

Period	Demand(MW)	MarketPrice(\$)	Uranium Cost(\$)	Coal Cost(\$)	Gas Cost	Biofuel Cost	Carbon Cost(Coal)	Carbon Cost(NOx)	Carbon Cost(Biofuel)
1	1998.00	66	1.00	4.00	9.00	3.00	2.0000	2.0000	0.5000
2	1998.00	96	1.00	4.00	10.64	3.00	2.0000	2.3640	0.5000

Period	Plant Num	Quantity	Price	Player
1	2	680	23	Tesla
1	1	60	45	Tesla
1	4	60	13	Bob
1	5	680	66	Bob
1	8	60	65	kofi
1	9	680	45	kofi
2	1	60	45	Tesla
2	2	680	96	Tesla
2	4	60	74	Bob
2	5	680	66	Bob
2	8	45	63	kofi
2	8	15	52	kofi
2	9	500	45	kofi
2	9	180	100	kofi

Figure 3. 9. Accumulated results for each period for all players

3.2. The player

3.2.1. Game Introduction

Registration and log-in procedure is the same for the player as that for the manager. The player must, however, select “Player” during role selection.



Figure 3. 10. Player's welcome page after logging-in

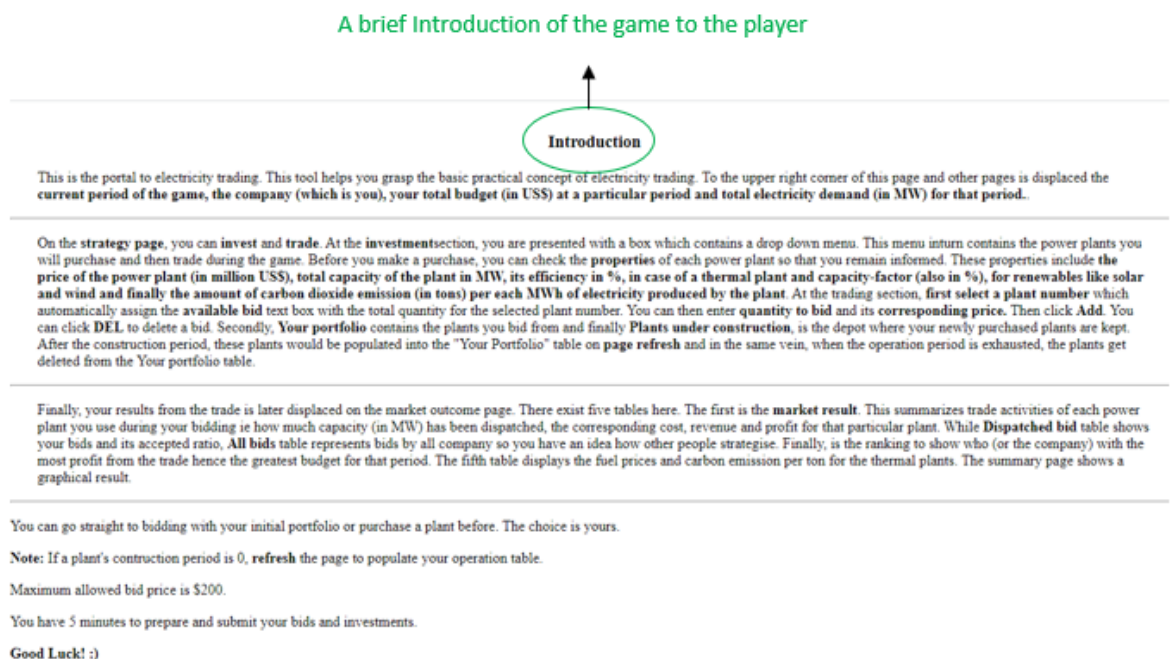


Figure 3. 11. Game introduction and explanation to the player

Figure 21 shows the welcome page (company information), displaying the player's username on the left and login date on the right. To introduce the players to the game prior to playing, Figure 22 presents a summary of the processes and procedures to be followed during the game. This serves as a guide to the successful gaming experience.

3.2.2. Investment in power plants

Figure 23 demonstrates the investment process on the strategy page. To invest, the player first selects a power plant after reviewing the plants and their properties in Figure 5. If the cost of the plant is in the range of the budget, it can be selected by clicking the add button. Investment can be done as long as there is enough budget. In the case the

cost of the selected plant is more than the budget, it can be changed for another plant or it can be canceled. The purchased plants are stored in the table shown in Figure 7.

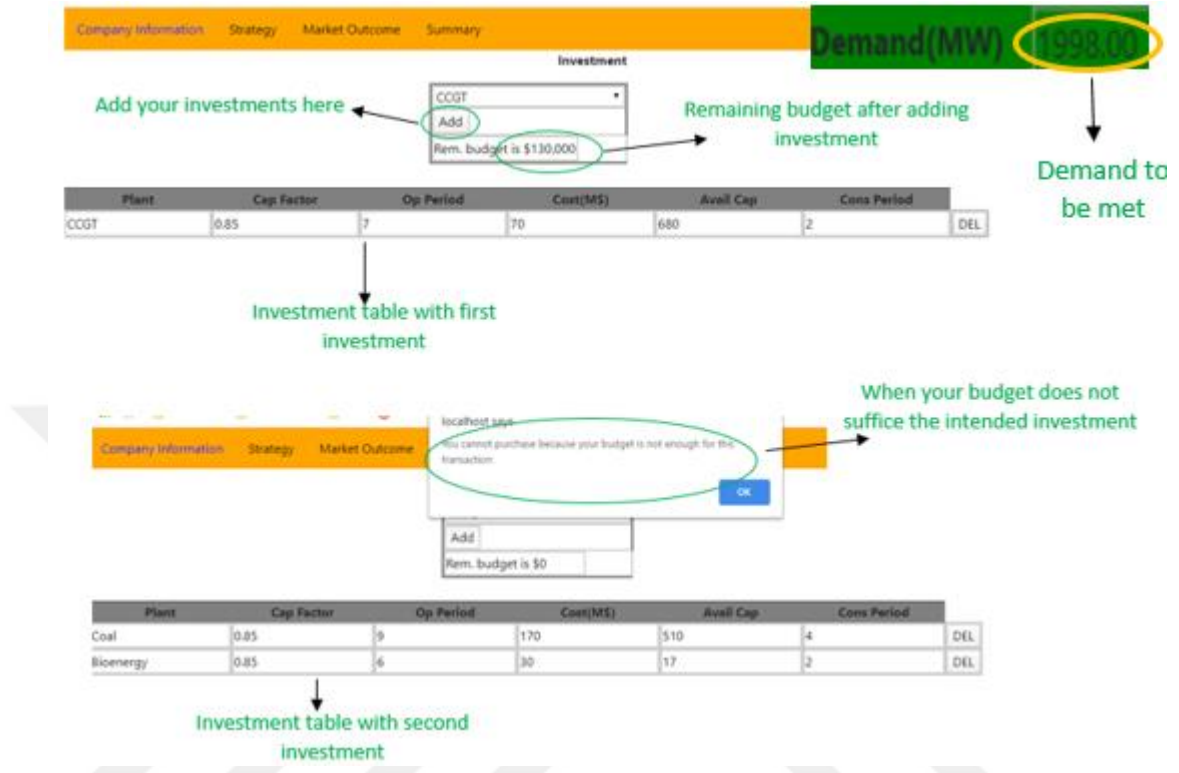


Figure 3. 12. Demonstration of the investment procedure

3.2.3. Trading

While Figure 24 just shows the framework of the bidding environment, Figure 25 is a step-by-step illustration of the bidding process. Even though more on bidding was already covered in the methodology chapter, Figure 25 shows a detailed pictorial view of the trading process.



Figure 3. 13. Depiction of the bidding segment

It is important to note that only numbers are allowed in the bidding fields. Moreover, the bidding price of more than 200 dollars is not permitted. Otherwise, the alert box prompts as shown in Figure 26.

As a rule, a player can only bid according to their total capacity; that is the sum of quantities of power plants available in the portfolio. When the sum of quantities of the bids exceeds that of the total quantity in the portfolio, an alert box is displayed, and bids cannot be submitted until extra bids are deleted. This is demonstrated in Figure 27.

1. Power plant number selection

Available bid Bid quantity Bid Price Add

Select Plant Number
8
9

Plant No Quantity (MW) Price (\$/MW)

Your portfolio				
Plant Number	Technology	Available Quantity (MW)	Operation Period	Offline In Period
8	Hydro	60	8	10
9	CCGT	680	6	8
Total: 740				

2. Automatic display of selected plant's capacity

8 60 Bid quantity Bid Price Add

Plant No Quantity (MW) Price (\$/MW)

Your portfolio				
Plant Number	Technology	Available Quantity (MW)	Operation Period	Offline In Period
8	Hydro	60	8	10
9	CCGT	680	6	8
Total: 740				

3. Inputting data to bid

8 60 45 63 Add

Plant No Quantity (MW) Price (\$/MW)

Your portfolio				
Plant Number	Technology	Available Quantity (MW)	Operation Period	Offline In Period
8	Hydro	60	8	10
9	CCGT	680	6	8
Total: 740				

4. Adding bid to bid table

8 15 Bid quantity Bid Price Add

Add bids here

Plant No	Quantity (MW)	Price (\$/MW)	DEL
8	45	63	

Bid table with first bid.

Your portfolio				
Plant Number	Technology	Available Quantity (MW)	Operation Period	Offline In Period
8	Hydro	60	8	10
9	CCGT	680	6	8
Total: 740				

Figure 3. 14. Demonstration of the bidding process

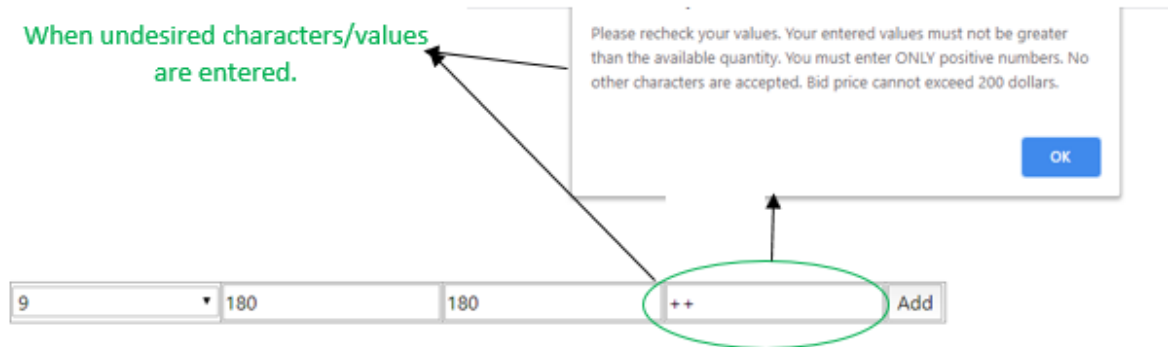


Figure 3. 15. Entering prohibited data into the bidding field

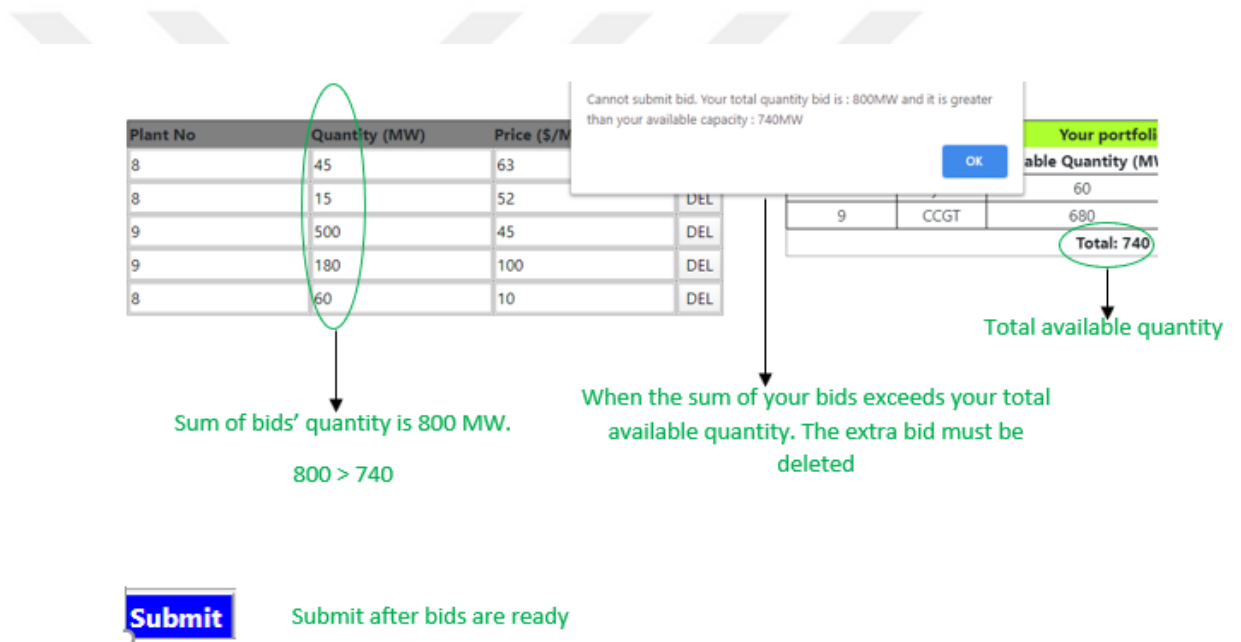


Figure 3. 16. Monitoring the total quantity of bids

After the bids are sent to the power exchange within the allotted time, various computations such as the cost, revenue and profit of each bid power plant (Figure 29), fuel price and carbon penalties (Figure 30), new budgets for each player with their rankings (Figure 33), and market price are completed. Also, accepted bids for each player (Figure 28) and all aggregated players are recorded (Figure 31). The dispatched ratio is included in Figures 28 and 31. This shows the amount of the bid quantity that has been accepted or dispatched. 100% means all the quantity is accepted and 0 means none is accepted because of its high bid price. Sometimes, the dispatched ratio is a fraction signifying that just part of the quantity is accepted. For example, in Figure 31, the accepted bid with a dispatched ratio of 0.9382 ($\approx 94\%$) is partial. The corresponding

quantity and bid prices are 680MW and \$96, respectively. Only 638 MW (0.9382×680) is dispatched. The sum of the product of quantity and its matching dispatched ratio must equal the demand; 1998 MW in this case (Figure 23), for the demand to be met. \$96 is the market price because supply meets demand at that price Figures 31 and 32.

Total demand: 1998 MW

Supply: $60 + 500 + 15 + 45 + 680 + 60 + (680 \times 0.9382) = 1997.976 \approx 1998$ MW.

Market price = \$ 96.

Plant Number	Quantity(MW)	Price(\$)	Dispatch ratio
9	500	45	1.0
8	15	52	1.0
8	45	63	1.0
9	180	100	0.0

Figure 3. 17. Your dispatched bids

Technology	Quantity Dispatched(MW)	Cost(\$)	Revenue(\$)	Tech Profit(\$)
Nuclear	0.00	0.00	0.00	0.00
Coal	0.00	0.00	0.00	0.00
CCGT	500.00	88,186,612.00	420,768,000.00	332,581,388.00
Hydro	60.00	66,666.67	50,492,160.00	50,425,493.33
Wind	0.00	0.00	0.00	0.00
Solar	0.00	0.00	0.00	0.00
Geothermal	0.00	0.00	0.00	0.00
Bioenergy	0.00	0.00	0.00	0.00

Figure 3. 18. Market result for each plant traded

Fuel	Unit Price(\$)	Carbon Penalty(\$/ton)
Uranium	1.00	0.0000
Coal	4.00	2.0000
Gas	12.58	2.7942
Biofuel	3.00	0.5000

Figure 3. 19. Fuel prices and carbon penalties for each plant traded

Quantity(MW)	Price(\$/MW)	Dispatch_Ratio
60	45	1.0000
500	45	1.0000
15	52	1.0000
45	63	1.0000
680	66	1.0000
60	74	1.0000
680	96	0.9382
180	100	0.0000

Fully accepted bids
partially accepted bids
Unaccepted bids

Market price

Figure 3. 20. Aggregated dispatched bids for all players

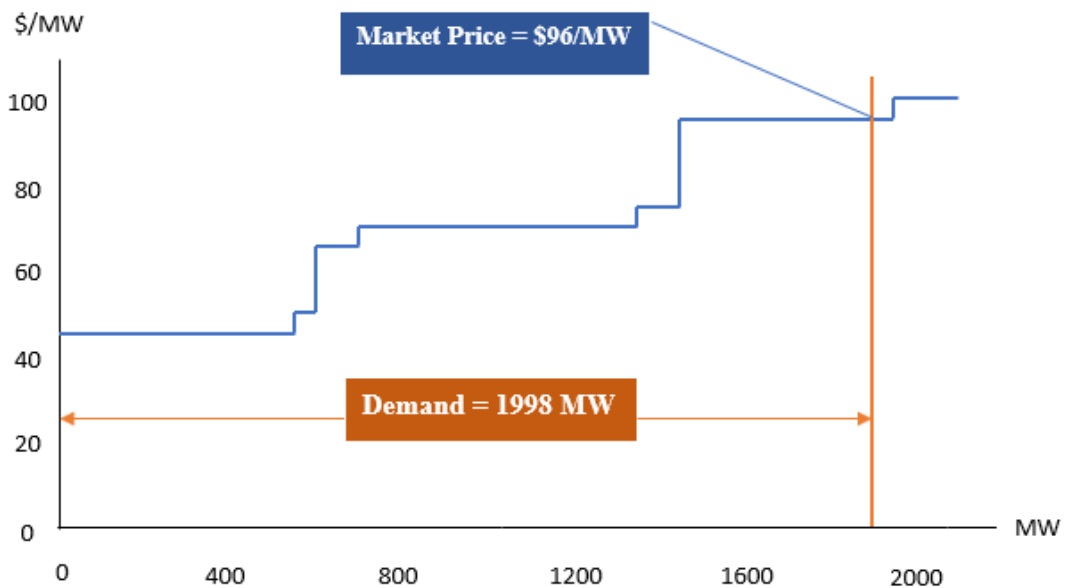


Figure 3. 21. Graphical representation of price-quantity pairs of all players

Player	Budget(\$)
Tesla	801,456,757.75
kofi	709,636,694.66
Bob	704,045,446.34

Figure 3. 22. Player's rankings

3.2.3. Result page

To further illustrate the results for the fuel prices and carbon penalties, graphs are sketched in Figures 34 and 35, respectively. These graphs show how prices for fuels such as uranium, coal, gas, and biofuel change over time and price of carbon incurred when these fuels emit carbon dioxide.

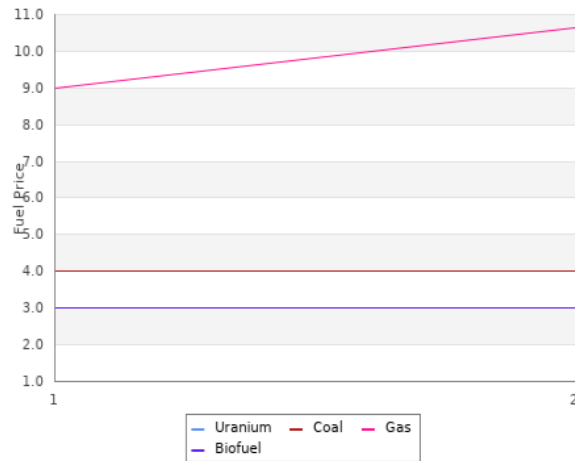


Figure 3. 23. Fuel Price Curve



Figure 3. 24. Greenhouse gas emission curve

To get the dynamics of the game concerning how the players decide their bid price, a graph for the market prices in also incorporated. This is shown in Figure 36.



Figure 3. 25. The market price curve

CHAPTER 4

IMPLEMENTATION AND RESULTS

The simulation game is used in two different courses given in the Department of Energy Systems Engineering at Erciyes University: (i) Energy Economics and Policy course and (ii) Energy Law course. Both courses are given at senior year and students usually take both courses in the same semester. There also have been some masters and Ph.D. students who audited these classes. Over 250 students played the game in several sessions after classical class sessions about the electricity markets and laws. Students are grouped as private generation companies consisting of 3 to 5 players and they decided on how to bid in the market and how to make an investment strategy. Each group played at least 10 rounds with 4 to 9 other groups. Each round in the game represents a year of the market.

To verify the effects of the electricity market simulation game, online questionnaires were sent after the game. A total of 86 students consisting of 82 undergraduate, 3 masters, and 1 Ph.D. students responded to the questionnaire. The questions tested their comprehension before and after the game session, how much of the simulation game they remember, their knowledge on general procedure of the game, knowledge on power plant investment, how they decide on the price-to-bid, how acquainted they are with the market price determination and their perspective on the game. Respondents remained anonymous to ensure truthfulness.

When asked about prior knowledge of students about the deregulated electricity trading before the game session, 52 students (59.8%) reportedly had little idea about the electricity trading which is due to classroom lessons they had on the subject, 31 students (36.8%) had no prior knowledge and only 3 students reported having a strong understanding of the electricity market trading system. Figure 37 illustrates these answers.

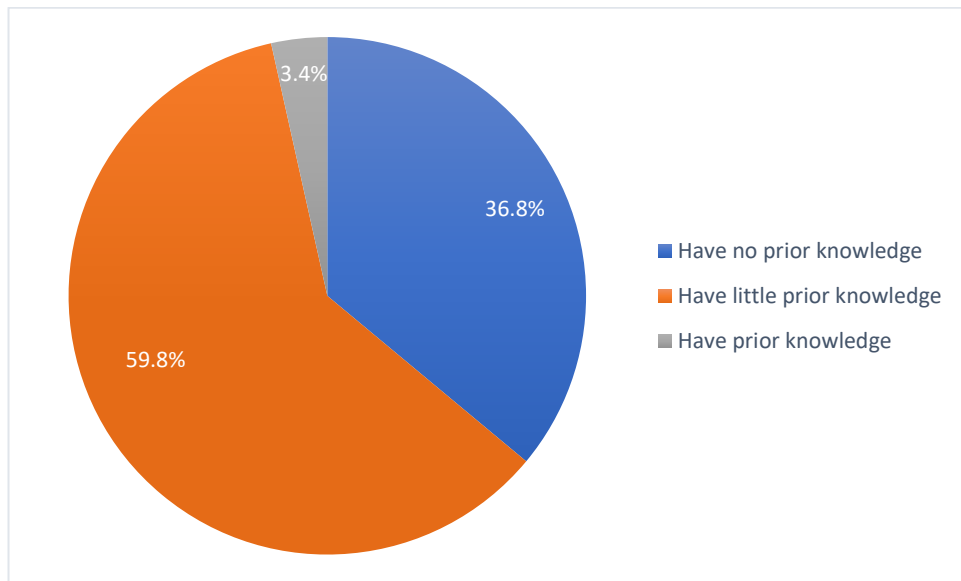


Figure 4. 1. Students' prior knowledge of the deregulated electricity market before playing the simulation game.

Before the students answer what exactly and how they understand electricity trading after the game, their recollection of the game was first assessed. To this, 16 people responded that they remember very clearly, 56 students stated that they remember most parts of the game, 12 students stated that they somewhat remember the game, and only 2 students stated that they remember nothing (Figure 38).

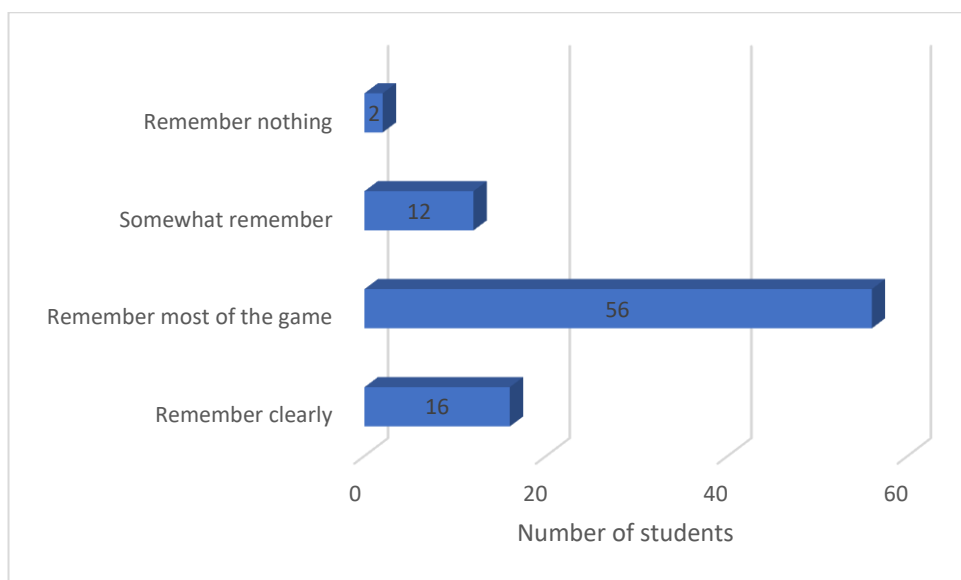


Figure 4. 2. Students recollection of the game

Representing 65%, 52 students stated that they understood the deregulated electricity market trading system clearly, 33 students (38%) stated that they somewhat understood

the system, and just 1 person stated that he/she did not comprehend the concept even after the game session.

On a scale of 0 to 5 where 0 and 5 represent “Definitely not understood” and “Definitely understood”, respectively, the students were asked to indicate their level of understanding of the electricity sales and determination of electricity price-to-bid, the investment procedure and how the market price was determined. The results are presented in Figure 39.

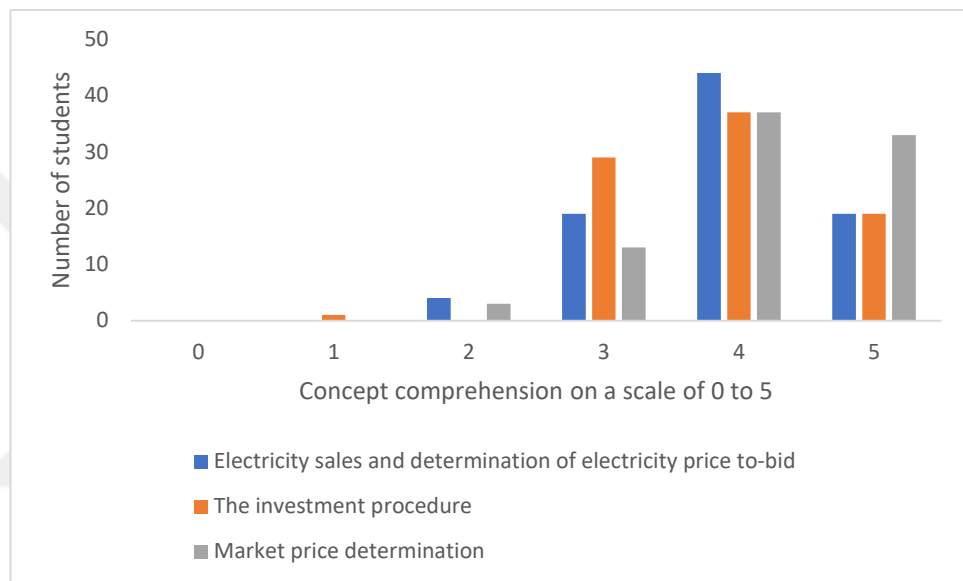


Figure 4. 3. The number of students who showed their level of understanding of various concepts on the electricity market on a scale of 0 to 5 after the game.

For electricity sales and determination of electricity price-to-bid, 19 students (22.1%) definitely understood (scale 5), 44 students (51.2%) chose scale 4, meaning they understood, 19 students (22.1%) somewhat understood (those who chose scale 3) and the number of those who chose scale 2 is 4, that is, they somewhat did not understand. Nobody selected 0 or 1. In the case of the investment procedure, 19 students (22.1%) indicated scale 5, 37 of them (43%) chose scale 4, scale 3 was chosen by 29 students (33.7%) and only 1 person chose scale 1. With regards to the market price determination, scale 5 was selected by 33 students (38.4%), 37 (43%) and 13 students (15.1%) chose scales 4 and 3, respectively. Only 3 students chose scale 2. Again, no student chose 0 or 1.

Figure 40 presents the general perspectives of students for the game. Most of them find the game fun, educative, and informative. Only one student found the game boring. One

other student stated that the game was difficult to understand. However, the same student stated that the game was informative. 73.8% of respondents stated that they wished other classes also adopt simulation games. This shows that students can be enthusiastic to learn about even a complex problem with simulation games.

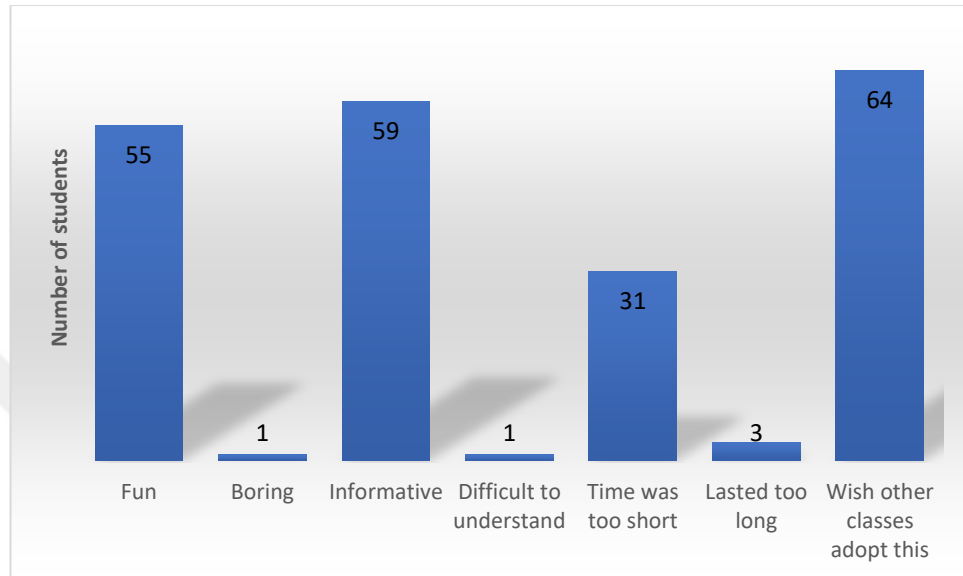


Figure 4. 4. Students perspective of the game

At the end of the questionnaire, students were asked to give their opinions on the game. Many students asked to improve the information session before the game. A detailed and clear presentation about the game before sessions start would increase the success rates.

The game is played in one session with several rounds representing years. Many students suggested playing the game for a few more sessions because they stated that the first session is spent to understand the concept. They asserted that their investment strategy would be different if they have played second or third sessions.

For further verification of the effects of the game, final examination results of the Energy Economics and Policy course given in the Department of Energy Systems Engineering at Erciyes University were analyzed. The results of 264 undergraduate students and their success on different types of questions were examined. There are 40 questions in the test in six different categories: (i) simulation game related bidding questions, (ii) cost calculation problems related to power plants, (iii) profit maximization problems related to power plants, (iv) Herfindahl-Hirschman Index (HHI) calculation and market analysis, (v) game theory questions and analysis, and (vi) a

theoretical question about Energy Economics and Policy. The overall test success was also computed. There are 15 simulation game questions and they are designed to assess student knowledge about the bidding process and market clearing. There are five questions about power plant cost calculation questions and students need to make detailed calculations about plant capacity, efficiency, fuel cost, carbon penalties, and investment costs. There are five questions about profit maximization and these questions require taking derivatives of profit and revenue functions. There are seven HHI calculation and market analysis related questions, and these are relatively easier than cost calculation and profit maximization problems. Game theory and analysis questions are related to a simple two-OPEC-country problem where countries try to maximize their revenue. There is one theoretical question, usually related to the definition of a term about energy economics and policy.

Figure 41 presents the average success of 264 students. The overall success in 40 questions is 76.78%. 212 students, representing 80.4% and the best success rate, were successful in the bidding questions. These results concur with the questionnaire results and literature that simulation games increase the understanding and performance of students.

181 students (68,4%) were successful in replying to the theoretical question. 185 students (70.2%) were successful in the cost calculation. In the case of profit maximization, 188 students (71.5%) chose the correct answers. Among other categories, students were the least successful in the theoretical question, the cost calculation, and profit maximization problems. These subjects solely covered in the classical classroom environment. HHI calculation and game theory success rates were 74.6% (197 students) and 80.1% (212 students), respectively. The game theory topic is covered in the classroom with a game played among students. Hence, the success rate is also similar to that of the simulation game.

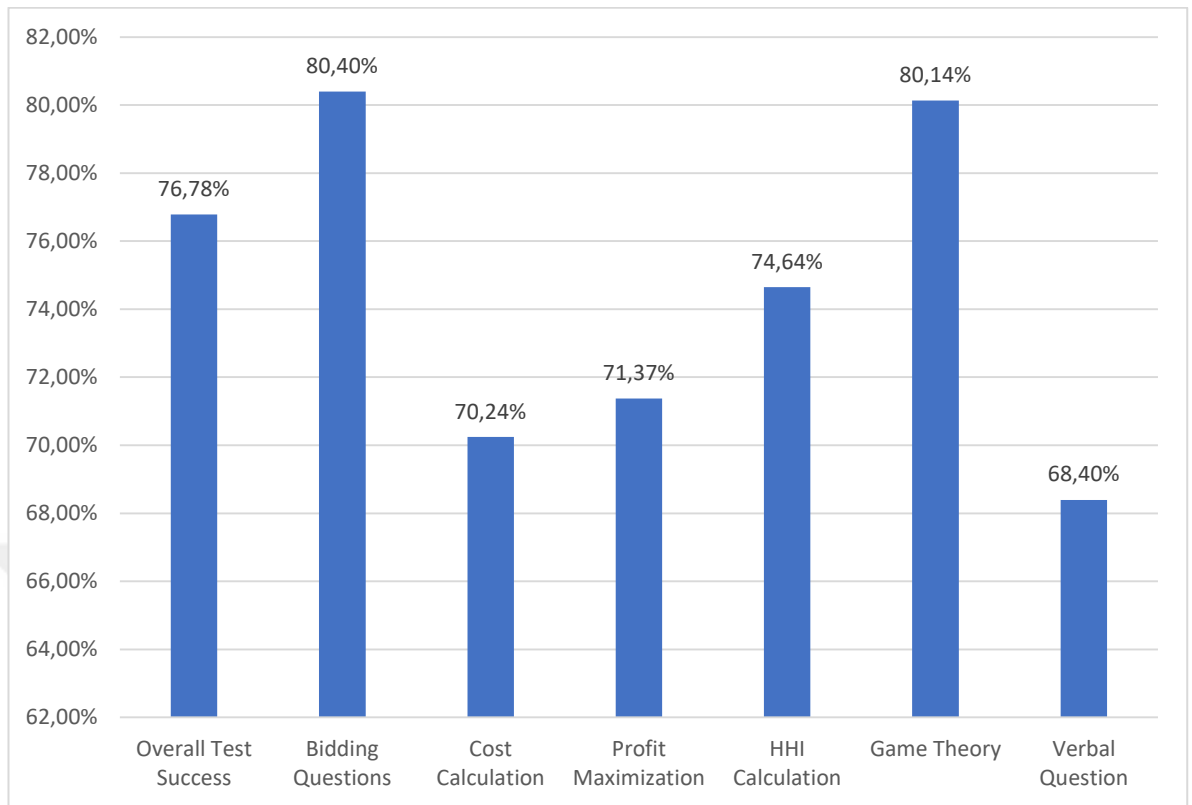


Figure 4. 5. Average Success of 264 Students

The game is implemented in the Energy Law course so that students can offer legal regulations to overcome the flaws of the simulation game. Students are asked before the game to observe the game process and potential flaws while playing the game. After the game, the groups are given homework to offer two legal regulations to fix the observed flaws of the market as simulated in the game. The legal regulations are asked to be written in the format of Turkish law. There have been several interesting ideas, however, most students focused on low prices due to the competition and excessive investments. Most groups offered some kind of price floor regulation because they observed that their profits are lost due to the low bid prices. The second most offered regulation type was on investment cap. Students observed that they have invested excessively at the beginning rounds of the game and this caused destructive competition towards the end and most groups suffered serious losses in the market.

The original idea of the Energy Law course was to implement the most voted legal regulation offer to the simulation game and to play one more session with the same groups so that students could observe the changes. However, this idea could not be implemented due to the high numbers of students and the limited class time.

Another purpose of the game is to observe player behaviors so that artificial intelligent agents can be designed for future research. We are still working on analyzing data for this purpose and the game will be modified accordingly.



CHAPTER 5

CONCLUSION

In this thesis, an electricity market simulation web application is developed. The main aim is to enhance the comprehension of students on complex concepts such as the deregulated electricity market. Results confirm the conclusion reached by numerous works of literature including [39] that simulation games are very useful for such complex concepts.

According to the results obtained from the questionnaire, only about 3% of the students had prior knowledge or understanding of the electricity market to the game session. After the simulation game, almost 98% of the students reported having understood the electricity market. About 95% percentage increase, which is impressive. This trend continued upon further detailed questioning of some specifics such as the investment process and the market price computation.

Test results of the Energy Economics and Policy course, where the game is used as a teaching tool, confirm the questionnaire results. Overall, students were the most successful in simulation game-related questions.

In conclusion, as stated in the literature, simulation games do improve understanding of intricate subjects or concepts because of the unique practice environment they present to the users than the usual pedagogical methods.

This research is no way near completion. The deregulated electricity trading is complex, its variants exist in different countries and it continues to evolve with time. Other extensions such as consumer side bidding, day-ahead trading, and carbon cap trading can be added.

Furthermore, the game created for this thesis will be used in research studies related to the electricity markets after developing and modifying it. Instead of or together with real

players, AI-agents, which can make strategic bidding and investment decisions, will be implemented to analyze different scenarios of the markets.



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