# GAMING AND SIMULATION FOR ENERGY SYSTEM INFRASTRUCTURE: A CASE OF THE POWER GRID SYSTEM


## ABSTRACT

The provision and distribution of electricity are necessary for the good functioning of society. According to DOE (2015), the electricity systems should be (1) reliable, (2) economically competitive and (3) environmentally responsible. Such a vision is not easily achievable, as these qualities may be in conflict with one another. Power system models are essential to simulate changes in the system and help resolve or mitigate conflicts. In this study, we present a gaming simulation, built upon a bottom-up discrete-event system model, to simulate the behavior and interactions of the main components in a power grid, forming various architecture scenarios. To develop this framework, we consider three main actions which the player can take, namely *build*, *retire*, and *expand,* to work toward an architecture with a more balanced weight of grid quality.



**Keywords:** gaming, simulation, energy planning


## 1 INTRODUCTION

The power grid system is a highly complex and heavily utilized network of components supplying, delivering and consuming electricity (IPCC 2007). This system is composed of generation stations which produce electrical power, transmission lines, which transport it from distant sources to demand centers, and distribution hubs which provide power to customers (Kaplan 2009). Throughout the world, it is one of the most densely driven networks (IEA 2016), yet its capacity has to increase further, due to the growing needs. Improvements in capacity management is increasingly difficult, given the urgent need to diversify energy resources, which requires a more elaborate and integrated planning process, taking into account the demand for electricity, flexibility to market changes, energy provision reliability, environmental impact reduction, and risk management of strategies considered (TVA 2015).

Existing systems of power provision and delivery need to change significantly, in order to address what the World Energy Council calls the “energy trilemma”: Ensure access to affordable (power should be generated and delivered in the least expensive manner), reliable (power should be delivered whenever, wherever and in whatever quantity needed), and sustainable (power should be generated with the least emission possible) energy for all (WEC 2016). Recent and anticipated trends indicate that renewable resources, particularly wind and solar energy, will be of a consistently growing contribution to global power systems (Mai et al. 2013). Formerly marginal renewable technologies like wind and solar are becoming mature and cost effective enough to justify grid scale investments (Khare, Nema et al. 2013).

Power grids must therefore adapt to handle renewable sources, which are unpredictable, and do not always produce as expected. This constitutes a reliability issue. A grid with 100% renewable would present low costs, as these sources have no fuel costs, but may not provide the amount of power needed, at the time and location needed. In such case, back up plants, which are mostly from conventional sources, are required. This will make the network less vulnerable to eventual drops in power generation from renewable. While such a grid will gain in reliability, it will lose in costs, as operating costs of conventional sources include fuel costs. In addition, there are also transmission costs that need to be accounted for.

The vulnerability of the electric power grid depends on its architecture, but also on the energy mix. Decentralized architectures systems are systems where components have some ability to operate "locally" (Johnson 1999), that is, components can make decision without a centralized control. In a power system composed of several zones, every zone would function independently of the other. Generators in this design would be built closer to consumers. They would include small- or medium scale, environmentally-friendly and traditional fossil fuel technologies primarily to serve a single area. This design increases the vulnerability of the grid, in case of break downs, and may lead to generalized power outage (Marnay and Venkataramanan 2006).

Centralized infrastructure systems have a central component that exercises control over lower-level components of the system (Bekey 2005). In a power system composed of several zones, certain zones may not be able to independently function (satisfy local demand) without others. In such system, power is generated in bulk, from a central unit, located at the point of best resource availability, and mostly away from end-users. Generators are mostly large scale and designed primarily to serve multiple and remote areas. They would offer improved local reliability (Zerriffi, Dowlatabadi, and Farrell 2007).

Energy planners have the task of designing an infrastructure power system to provide electricity to population, at a given set of locations. Eventual actions may include the (1) increase in redundancy and capacity of current generating units, or (2) decrease of the reliance on transmission by furthering the use of more distributed generation (Albert, Albert, and Nakarado 2004). Deciding the option to take will have serious implications given that the power system reliability and the future shape of that system are at stake. These implications may yield deeper insight into complex issues, namely expansion of power system infrastructure, or its potential transformation over time. What type of architecture is needed, if the objectives are, not only to minimize costs, but also minimize environmental effects and maximize reliability? This issue is even more pressing now that nations across the globe are heavily investing in the use of renewable sources to match the rising demands (IEA 2014).

Gaming simulation has evolved to become the most apt tool for designing computer-mediated interaction among policy makers (Meijer 2009). One of its essential features is the ability to bring together the system's technical complexity with socio/political complexity surrounding decisions (Mayer 2009) and enable the player to find the balance. To some extent, gaming makes up for the weakness felt in Modeling and Simulation, that is, the lack of transparency in certain energy systems models (Dodds, Keppo, and Strachan 2015). It has the ability to open up the black box and help improve policy-oriented learning (Cecchini and Rizzi 2001). The player is immersed in an experiential learning environment, which provides him with clues to identify sensitive conditions of the system operation, a sense of what (not) to do to attain the objective, as well as short-term and long-term repercussions.

Learning is a key objective of simulation games (Girard, Ecalle, and Magnan 2013; Padilla et al. 2016). Via experiments and scenarios, the player can grasp the underlying mechanism of the system and eventually explain the changes occurring. In the gaming sessions, players will be able to identify key elements of the power system, and eventually assess their (in) direct influences. Dray et al. (2007) argue that in these sessions, tacit knowledge is made explicit through the players' choices of action, furthering the understanding of the deep lying connections between components of the system.

In this study, the player is confronted with the task of designing a grid which would present the best balance between reliability, sustainability and affordability. Three options are available to modify the architecture of the power system: *retire*, *build* and *expand*. *Retire* refers to shutting down generating and storage units. *Expand* refers to augmenting the capacity of generating units, and the limits of transmission units. *Build* refers to building a new power plant, storage unit, or transmission line. These decisions can be taken in isolation or as a group. This paper presents a sample game scenario promoting actions at the network level, in order to take full advantage of transmission lines and large scale renewable. We hope to stimulate new reflections to help understand the impact of different power grid architectures on economic, environmental and reliability performances.

Section 2 gives a brief definition of the concept of gaming simulation. In section 3, we present the underlying model used for the simulation, and discuss its characteristics. In section 4, we present a game session where players have the opportunity to interact with the game. Section 5 and 6 propose a brief discussion regarding the bien-fondé of this approach, and a conclusion, respectively.

## 2 GAMING SIMULATION

According to Bratley, Fox, and Schrage (2011), simulation is the act of "driving a model of a system with suitable inputs and observing the corresponding outputs". Simulation thus involves, not only modeling, but also experimenting. A model is a simplified representation of the real system, specified in space and time (Phan and Butler 2008). After the model is designed, it is executed over time via simulation. Simulating the model would help analyze its behavior through experiments and reach some understanding. It displays the variations of the state of the model's variables over time and ultimately evaluates the performance of the system, under different configurations (Maria 1997).

Gaming is a form of play, in which players have objectives to reach and roles, that is, they take responsibility through fictional characters to act, via a process of structured decision-making (Cover 2010). Gaming offers fair rules and clear goals, as well as incentives or winning prizes to learn from mistakes and eventually develop the knowledge and skills necessary to fulfill the pursued goals.

Adding gaming to simulation means adding human interaction to control experiments and increase validity (van den Hoogen and Meijer 2015). A gaming simulation becomes a model of reality, with the roles, rules, objectives and constraints similar to the real world. The behavior observed in a game session is therefore a somehow faithful representation of the behavior of decision makers in the real world. It is a simulation of the repercussions of decisions made by actors holding roles and prerogatives with explicit references to aspects and structures that realistically express the existing infrastructure and resources (Kriz 2003). Gaming simulation would thus serve as a tool for bringing diverse insights together, laying out various approaches to a problem and allowing different alternative to be experimented in a safe environment (Meijer 2012). In the case of this study, actions taken by players convey the need for the grid to be as reliable, environmentally friendly and as affordable as possible. However, ways to arrive at that point, if at all possible, would vary, given the different perspectives of the players. The goal here is to simulate the actors' decision-making process and show the consequences within the system.

## 3 POWER SYSTEM MODELING

Building a gaming simulation platform follows three steps: (1) model the real system, (2) enable and facilitate human interaction while controlling the research environments via scenarios, and (3) identify outcomes of the system that may warrant actions from decision makers (Lo, Van Den Hoogen, and Meijer 2013). It is therefore critical to build a good model, as it will determine the credibility of the results and the confidence of players or decision makers to adhere to the reasonableness of these results. As modelers, the most important task is to balance model details and system complexities (Dodds, Keppo, and Strachan

2015), that is, make sure the model captures all salient components and phenomenon of the system in a simple and realistic manner.
In practice, a good model is the one which strikes the right balance. In our effort to reach this goal, we follow the requirements suggested by Mader, Wupper, and Boone (2007), to build our power system model. The model used is *Spark!* (Toba et al. 2017).

*Object of modelling* — what does the model describe? *Spark!* describes the behavior of the power system.

*Purpose* — what is the model purpose? *Spark!* 's main goal is to perform energy planning, by analyzing expansion plans on a long term while also performing day-to-day activities of the system, on the short term.

*Traceability & Truthfulness* — are key properties and components of the system represented in the model? *Spark!* captures the intermittence and stochastic nature of renewable energy resources, the technical constraints of conventional generation resources, geographical information, transmission network system and operating reserves. It also captures the salient components of the power grid, namely supply, load, transmission and distribution. In addition, the model performs a security constrained unit commitment with a flexible look-ahead period, and a stochastic economic dispatch, using an enhanced Priority List method.

*Extensibility and reusability* — can the model be used beyond its original purpose and are its output replicable? *Spark!* is developed in the python language following the DEVS framework, using the PythonPDEVS library of components. These model components are instances of generic Python® classes, representing the components present in a power system. This way, the model does not only describe the specific system at hand, but also, given appropriate instantiation and scaling, is able to model systems of similar nature.

# 4 LET THE GAME COMMENCE

## 4.1 Game Structure

The players interact with the gaming platform, via an interface (Figure 2). They can log in and out using personalized data. Bars at the top provide general information regarding the current grid (e.g. number of generator and zones), and the number of registered users (other players) and online subscribers. On the left, the panel displays options available to the player. Under the tab planning, players can choose to add new constructions, retire and/or upgrade generation, transmission as well as storage assets. On the lower right corner of the panel, the map reflects the changes in the grid architecture. The pie chart in the metrics panel displays the generation mix, that is, the proportions of technology generation type composing the total supply used to fulfill the demand in the whole network. The scenario progress bar indicates how far in the scenario the player is. If a scenario is ten years long, every year of simulation will count for 10% in the scenario progress bar.

Figure 1 illustrates the structure of the game. Players can take actions as only allowed by the game rules. The player's decisions represent inputs. In figure 3, players for instance, decide to build a new power plant. Input are data entered by the player, specifying zone, name, technology type and capacity of the plant to be built. Once entered, the grid is simulated via *Spark!* , and resulting performance are computed. The outputs are displayed on the interface to allow players to assess the implications of their actions (figure 1).

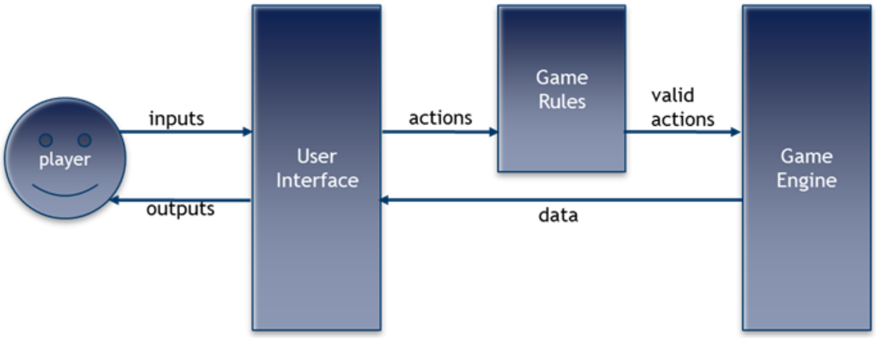


Figure 1: Structure of the game

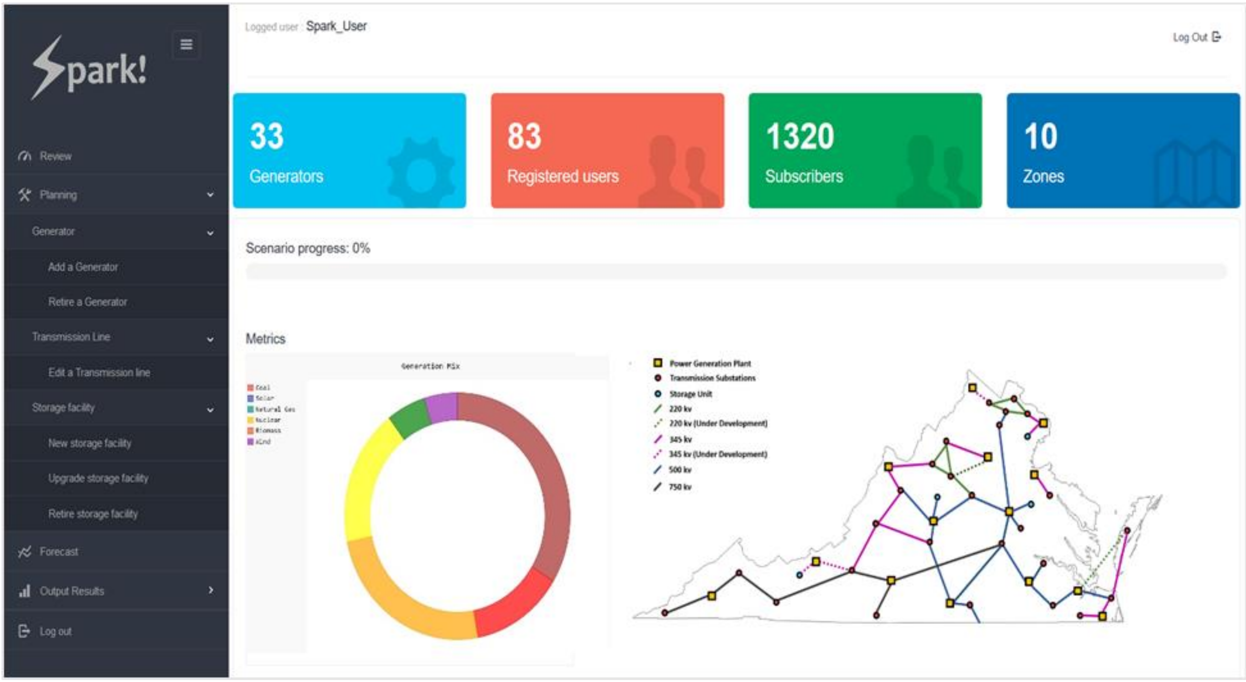


Figure 2: Game interface

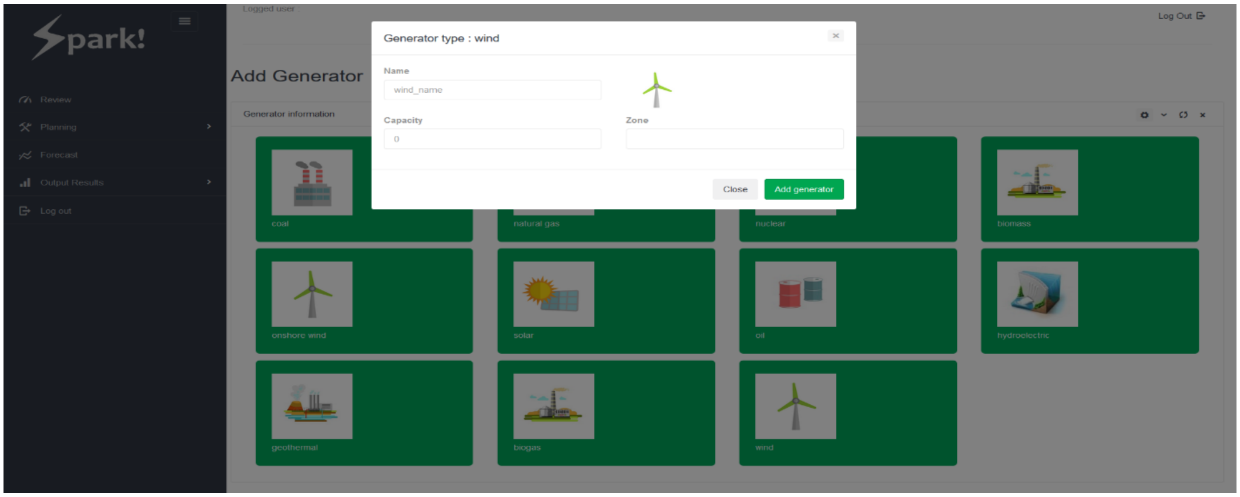


Figure 3: Building a power plant

## 4.2 Game Session

In each session, the player is presented with a specific situation. For illustration purposes, we present a grid with 33 power plants, with various power generation technology including natural gas, biomass, coal, solar, nuclear, biogas, hydro and oil. In this game scenario, transmission lines capacity is considered limitless, that is, electricity can be exchanged between zones, as much as there is. A zone is considered to be a location with a specific load pattern, a distribution system and a generation fleet. The grid network is composed of several zones. The scenario simulation run is 8 years, with human interaction taking place at every year. Players are presented with an initial grid, with a specific generation mix.

The goal of the game is for the player to create a grid with maximal profit and minimal emissions. The player does so by adding or retiring power plants. A plant added is assumed to be available in the same year for subsequent simulation run. The player is provided with information regarding fuel costs, capital costs, fixed and variables costs as well as emission rates for each generation technology, so as to help him in the decision making.

Table 1: Generation fleet of initial grid

| Name | Zone | Type |
|---|---|---|
| Plant1 | Valley | Biogas |
| Plant2 | Valley | Biogas |
| Plant3 | Valley | Biogas |
| Plant4 | Valley | Coal |
| Plant5 | Valley | Solar |
| Plant6 | Hampton Roads | Coal |
| Plant7 | Hampton Roads | Coal |
| Plant8 | Hampton Roads | Coal |
| Plant9 | Hampton Roads | Natural Gas |
| Plant10 | Hampton Roads | Natural Gas |
| Plant11 | Hampton Roads | Biomass |
| Plant12 | Hampton Roads | Solar |
| Plant13 | West Central | Coal |
| Plant14 | West Central | Coal |
| Plant15 | Northern | Natural Gas |
| Plant16 | Northern | Nuclear |

Table 2: Generation fleet of initial grid (Continued)

| Name | Zone | Type |
|---|---|---|
| Plant17 | Northern | Nuclear |
| Plant18 | Northern | Nuclear |
| Plant19 | Southside | Oil |
| Plant20 | Southside | Oil |
| Plant21 | Southside | Solar |
| Plant22 | Southside | Hydroelectric |
| Plant23 | Central | Biogas |
| Plant24 | Central | Solar |
| Plant25 | Southwest | Coal |
| Plant26 | West Central | Nuclear |
| Plant28 | West Central | Solar |
| Plant29 | Eastern | Solar |
| Plant30 | Eastern | Solar |
| Plant31 | Eastern | Nuclear |
| Plant32 | Eastern | Nuclear |
| Plant33 | Eastern | Oil |

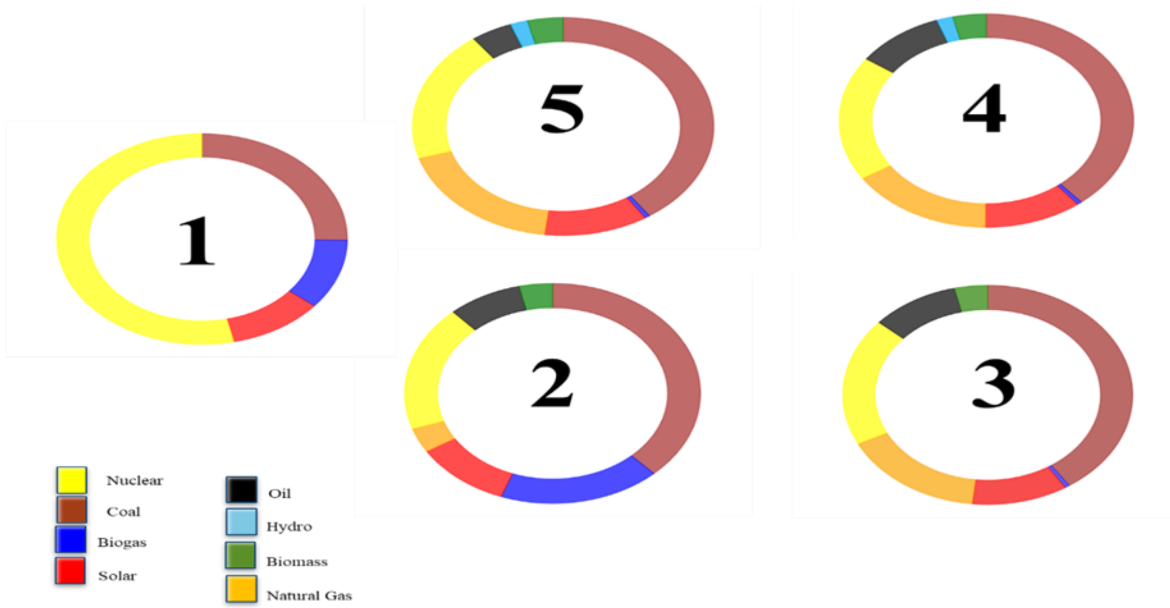


Figure 4: Generation mix

Table 1 and 2 display the generation fleet in the initial grid. Figure 4 displays generation mix outputted to the player, with (1) being the mix of the initial grid, (2) the mix at year 2, (3) the mix at year 4, (4) the mix at year 6, and (4) the mix at year 8. The player attempts to reduce its nuclear energy, and at the same time increase the use of renewable. It leads to a more pronounced use of coal, given its relatively low capital investment and variable costs, compared to natural gas or nuclear. The use of oil also emerges as nuclear plants are phased out. The player also engages in the building of solar and hydro power, as the scenario evolves.

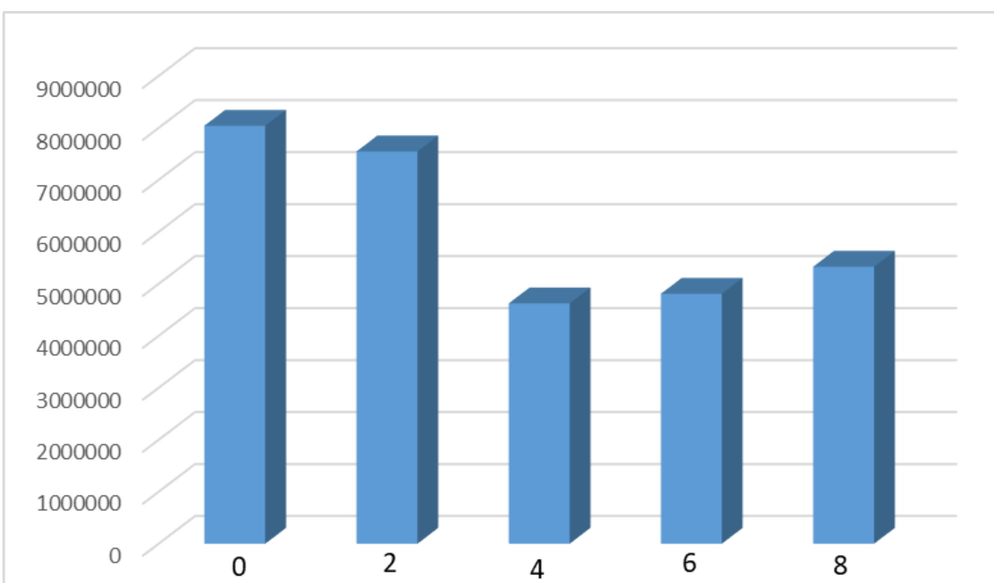


Figure 5: Financial performance of the grid ($)

These actions have economic implications. Figure 5 displays the overall financial performance of the grids designed by the player during this scenario. These represent profit/loss generated, considering all expenses made (capital costs, fuel costs, fixed and variable O&M costs) and revenues (costs at which electricity is sold). The profits are going down at year 2 and 4, with increased use of coal and oil, which reflect the high cost of transporting coal to centralized power plants and the expensive pipeline to reach faraway markets. The profits later appear to remain relatively stagnant, with the use of hydroelectric sources and a slight reduction in oil use.

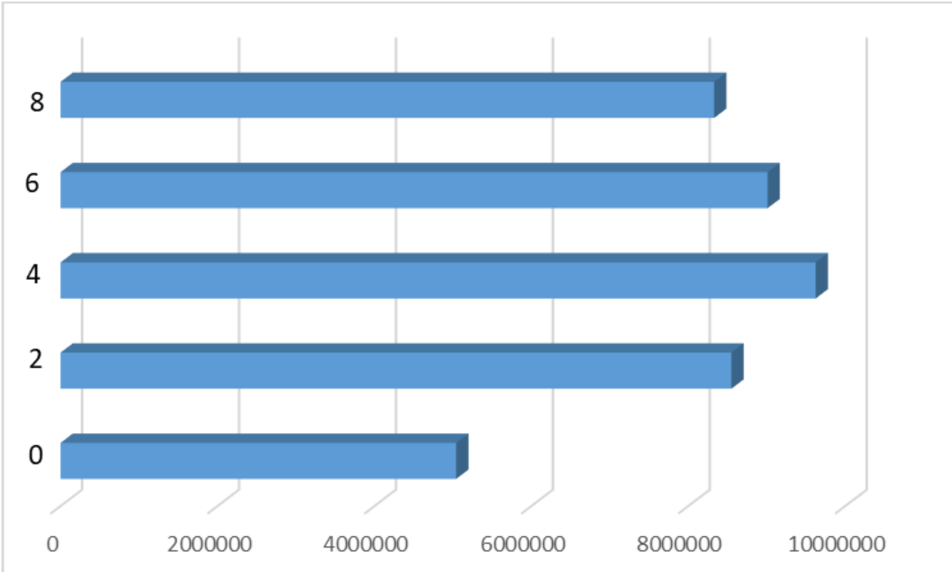


Figure 6: CO2 Emission (lbs)

The player can also have a sense of the amount of gas emissions, here $CO_2$ (carbon dioxide), caused by the generation fleet composing the grid (Figure 6). At year 2, the $CO_2$ emissions considerably go up, given the high use of coal, biogas and oil. Year 6 shows a slight decline considering the introduction of hydroelectric power and the reduction in use of coal. This decline is also felt at year 8 with less oil in the energy mix, and despite a small increase in use of natural gas.

## 5 DISCUSSION

Today's power sector is an extreme example of a co-evolving complex dynamic system in transition, characterized by path dependency, and changes in institutions, technological innovation, consumption pattern and environmental. Complex engineered systems, like power systems, come about as a result of historical, institutional and behavioral lock-ins and path-dependent technological development trajectories (Simmie 2012, Fouquet 2016). Current decision-making on strategic planning is thus made up of outcomes from past choices, even though they may no longer be relevant, and several other factors which behavior or future changes may be unknown. Decision makers are constrained in their ability to take actions, by (1) a limited, often unreliable, information concerning possible alternatives and their implications, (2) a limited capacity to understand available information, and (3) a limited amount of time, with the expectation of a satisfactory outcome. It is critical to understand, or at least strive to, how power infrastructure systems co-evolve with Society (populations, policy, institutions, economy, etc.) and nature (resources, ecosystems), and understand how best influence this co-evolution. One avenue would be to balance the needs expressed by society and the resources available, or at least, examine situations in which this balance or stability can be reached, if at all possible. We posit that gaming simulation is an effective way of developing this avenue.

The gaming simulation approach used in this research, is to teach/learn concepts in power system management. Players could use the game as an experimental setting, providing, not only insight into the functioning and operations of a grid, but also context for players to improve skills in resource planning through rules, roles and various scenarios. It is our expectation, using this approach, to draw all generations of learners to become more excited about the power sector. More importantly, we hope this framework can help raise awareness of the complexities enclosed in power grid operations for future generations to come. The game focuses on the competing objectives, designed here as performance of the system, namely environment, costs and reliability. The race for use of renewable sources is fierce and may lead to design choices that are not always the least costly or most reliable. The platform presented captures this aspect of the system and provides the player options to mitigate conflicts, in a fun and learning environment. The player is exposed to a multitude of decision factors, affecting, not only the organization of information but also its understanding. This shapes learning.

## 6 CONCLUSION

This paper documents efforts in teaching power system planning via gaming simulation. It is argued that simulation gaming provides an entry point, not only for novice, but also experts (Padilla et al. 2016), in the field of energy system management. With mounting demand for power, challenges linked with supply, and concerns over sustainability, there is an undeniable need to ensure that practitioners and new learners gain a holistic comprehension of concepts relevant to energy management. A scenario is presented, in which a player takes action in order to build a grid that is environmentally friendly, least costly and reliable. The player is placed in a gaming environment, where real situations are replicated, and implications are readily assessed.

Future work includes a more systematic process to evaluate the effectiveness of simulation-based gaming for energy systems questions in order to assess the contribution of this approach to problem solving. It could help get information about how realistic the game is, and what could be added to position gaming simulation as a bridge between laboratory and field experiments.

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