Energy Policy 102 (2017) 170–188

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

A dynamic simulation model for assessing the overall impact of incentive policies on power system reliability, costs and environment

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ARTICLE INFO

Keywords:
Capacity payments
Incentives
Reserve margin
System costs
CO_2 emissions

ABSTRACT

The liberalization of power markets has entailed dramatic changes in power system planning worldwide. The inception of new alternative technologies, smart grids and distributed generation and storage is expected to make system planning even more challenging.

Government policies still play a major role in the evolution of a country's power generation mix, even in those countries with liberalized markets.

This paper presents a System Dynamics model aimed at assessing the overall technical, economic and environmental impact of renewable energy incentives and capacity payment policies.

The model has been used to simulate Spain's power industry in order to assess the impact of electric power policies with the goal of getting insights regarding how to achieve an optimum power generation mix.

The main conclusions of the present paper are (i) the necessity of specific regulatory actions in Spain in order to keep adequate reliability levels, avoid price spikes and boom and bust investment cycles as well as to deploy specific technologies, (ii) the fact that capacity payments are a better instrument for keeping adequate reserve margins and avoiding power price spikes than renewable energy incentives and (iii) the evidence that both instruments entail additional system costs over the base case scenario.

1. Introduction

The liberalization of power markets started in the late 1980s when Chile, Norway and the UK first introduced competition in their electricity markets (Gary and Larsen, 2000) and has since become a growing trend worldwide. This fact has entailed significant changes in how power system planning is carried out as the industry has evolved from a monopoly to an unregulated model which is driven by supply and demand market forces.

While some of the main characteristics of the power industry during the monopoly era were stable prices, full information, easily forecasted demand and co-operative regulation, liberalization has introduced new characteristics such as price volatility, limited information and uncertainty (Dyner and Larsen, 2001; Gary and Larsen, 2000).

Also, the power industry is experiencing changes never seen before which are adding complexity to the planning and forecasting processes. These challenges include the inception of renewable technologies such as wind and solar with their associated variability, the introduction of the electric vehicle, the inception of distributed generation, the potential introduction of distributed power storage (Castelvecchi, 2015) and the obsolescence of systems such as the nuclear power plants built in the 60s and 70s.

Power system planning aims basically at providing a reliable service (i.e. keeping stable and adequate reserve margins) while keeping costs as low as possible. In addition, some specific markets (e.g. the EU) have specific environmental goals. While centralized planning can accomplish these goals relatively easily, liberalized markets entail additional challenges. There is extensive research (Ford, 1999, 2001a; Bunn and Larsen, 1992; IEA, 2014) showing that market forces may not be enough in order to keep investment levels high enough to maintain safe reserve margins or to achieve specific environmental targets. So, governments must introduce instruments such as incentives or capacity payments in order to drive the power industry in a way these goals are achieved.

Despite the current declining costs of some alternative power generation technologies (e.g. wind and solar PV), regulated incentives still play a major role in their deployment. While in some locations the available energy resource (e.g. wind speed or solar irradiation) is enough for alternative technologies to be fully competitive with conventional ones, regulated incentives are still required in order to

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http://dx.doi.org/10.1016/j.enpol.2016.12.026
Received 23 March 2016; Received in revised form 22 October 2016; Accepted 13 December 2016
0301-4215/

Table 1
Main citations on SD applied to power markets.

(Bunn and Larsen, 1992)	*Provide insights regarding how the investment in generation capacity may evolve according to different regulatory conditions, economic assumptions, degrees of competition and strategic behaviour of utilities in England and Wales. It focuses on impact on reserve margin and gas CC technology.*
(Bunn et al., 1993)	Discuss that optimization techniques are more suited for simulating rate of return, capital structure and tax implications due to the deregulation of power systems while SD is more useful for simulating the regulatory, uncertainty and competitive effects.
(Ford, 1999) and (Ford, 2001a)	Uses SD to assess the impact of capacity payments on investment boom and bust cycles and analyse California´s 2000 and 2001 power market crises. The studies focus on the impact of capacity payments and are limited to investments in new gas CC capacity.
(Gary and Larsen, 2000)	Discuss the advantages of dynamic simulation methodologies such as SD over equilibrium models for the simulation of markets in transition.
(Kadoya et al., 2005)	Assess the impact of deregulation on generation capacity growth and show that deregulation is a driver for the boom-and-bust cycles that occurred in the US in the nineties. The full technology range is considered and the dispatching process is modelled although impacts on system costs or environment are not considered.
(Ford, 2006)	Presents an interdisciplinary approach that combines SD and engineering methods in order to simulate a cap and trade market aimed at controlling the emissions in the US western electricity system. Focuses on CO_2 emissions and considers gas CC, coal, wind and biomass technologies.
(Olsina et al., 2006)	Focus on the formulation of a mathematical framework which extend previous SD models for long term power system planning.
(Arango, 2007)	Uses SD in order to evaluate alternative regulation schemes regarding capacity payment for the Colombian electricity market, focusing on hydro, gas and coal technologies.
(Sanchez et al., 2008)	Combine a SD model with an oligopoly model, so that generator market power is considered, for forecasting reserve margin and power price.
(Garcia Alvarez et al., 2008)	Describe a model of the Spanish power industry aimed at assessing whether the market price and current capacity payments are enough for achieving the required reserve margin. Technology breakdown is not assessed.
(Assili et al., 2008)	Simulate and explore an improved mechanism for capacity payment in a competitive environment. The study considers gas CC, gas peak and coal technologies.
(Hasani and Hosseini, 2011)	Present a model aimed at examining the performance of electricity markets under different capacity payment mechanisms. The study considers gas CC, gas peak and coal technologies.
(Pereira and Saraiva, 2011)	Present a model aimed at solving the generation expansion planning problem in competitive electricity markets by using a combination of SD and Genetic Algorithms which is applied to the case of Portugal. It focuses on thermal, wind and hydro technologies.
(Hsu, 2012)	Uses a SD approach for assessing the impact of incentives on the development of PV power, CO_2 emissions and costs in Taiwan.
(Alishahi et al., 2012)	Use SD to study the evolution of wind power as a function of different incentive schemes.
(Saysel and Hekimoglu, 2013)	Use SD in order to explore policy options for carbon mitigation in Turkey's power industry, such as carbon pricing, RES tax incentives and fast RES permitting.
(Qudrat-Ullah, 2013)	Introduces a SD model in order to assess the evolution of Canada´s power generation mix, power price and capacity gap from a macro perspective which includes R & D efforts.
(Robalino-Lopez et al., 2014)	Use SD in order to assess the impact of the power generation mix on CO_2 emissions at a macro level in Ecuador.
(Kunsch and Friesewinkel, 2014)	Use SD for assessing the impact of the Belgian nuclear phase-out law on the power generation mix, power price, oil dependency, CO_2 emissions and power demand.

make alternative technologies competitive in other locations.

Defining appropriate policies is a key issue in order to avoid over or underinvestment as it has been the case in countries such as Spain (Prieto and Hall, 2013). Power generation projects show a large inertia due to facts such as the long planning and development times, the time required for investors to make expectations and investment irreversibility which, in some cases, makes investors delay investment decisions in order to take advantage of the value of their option to invest.

Due to the challenges introduced by deregulation as well as due to the difficulty in making experiments in the energy policy field, the use of models in order to get insights regarding the long term impacts that energy policies may have under new unregulated environments becomes very useful.

This work presents a System Dynamics (SD) model developed with the abovementioned goals. The present approach builds on the existing literature by presenting a comprehensive approach which combines the SD methodology with a full merit order pricing model in order to compare the overall impact that capacity payments and alternative energy incentives have on system costs and environment in the case of Spain's power system. Additional modelling refinements such as technology specific threshold IRRs, the consideration of technology learning curves or the consideration of the whole power generation technology spectrum have been also considered.

2. Methods

2.1. Introduction

Diverse optimization techniques such as linear and integer programming, game theory, real options, decision trees and forecasting have been traditionally used under centralized market environments in order to optimize investment decisions on power generation capacity additions (Dyner and Larsen, 2001; Kagiannas, et al., 2004). Also, econometric methods have been widely used in order to describe the statistical relationships between economic variables and provide forecasts in power markets.

The transition from regulated to deregulated markets has entailed two relevant changes in the capacity expansion process as (i) utilities had to switch from traditional optimization-based planning to strategy-based planning and (ii) the planning capacity expansion process has been reformulated from a cost-minimization problem, where the goal was to determine the right level of generation capacity, the optimal mix of technologies and the timing of investments at a minimum cost and adequate level of reliability (Olsina et al., 2006), to a profit-maximization problem (Kagiannas et al., 2004; Hasani and Hosseini, 2011). This transition entails the necessity to switch from "hard" modelling and optimization techniques to models which include "soft" variables such as market perceptions, public opinion, politic interests and bounded rationality (Larsen and Bunn, 1999; Gary and Larsen, 2000; Dyner and Larsen, 2001; Olsina et al., 2006; Assili et al., 2008). In addition, the use of econometric methods based on large historical datasets becomes difficult as new liberalized power markets have had a short life so that there is not much historical data available.

Different kinds of mathematical methods have been under development during the last years in order to facilitate decision making on power generation capacity expansion. Short and medium-term models are the ones which have experienced the largest development (Sanchez et al., 2012). On the other hand, long term models are still a more unexplored area (Kagiannas et al., 2004).

Both Agent Based Modelling and SD belong to the group of dynamic models that focus on understanding the interdependencies of the different variables in a system. On the contrary to optimization models, this kind of models include "soft" variables such as perceptions of reality, beliefs about the behaviour of market players or management