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Nuclear and old fossil phase out scenarios: Assessment of shortages, surpluses and the load factor of flexible assets with high renewable generation targets – A Belgian case study

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ABSTRACT

In the coming decades Belgium will phase-out nuclear and old fossil capacity while (intermittent) renewable generation is expected to increase. We evaluate the occurrence of electricity shortages and surpluses in Belgium in 2013 and 2017, as well as the evolution of the load factors of flexible assets. Our statistical model for 2017 suggests surpluses of >2000 MW during 4% of the time. More alarmingly, the combination of an unfavorable investment climate and a nuclear phase-out plan will increase the probability of the occurrence of shortages in the near future. Therefore we suggest adapting the current priority dispatch policy for renewables in order to improve the investment climate for flexible assets and reduce the surplus risks.

Introduction

The Belgian case

Belgium has 7 nuclear reactors with a combined capacity of about 6000 MW, resulting in a share of roughly 50% of nuclear electricity production in the Belgian electricity mix in a normal year [12]. These reactors were all built in the 70s and 80s and are thus reaching their end of life. Since the beginning of the century, the Belgian government has been debating the phase-out of these nuclear assets. In the summer of 2013, the Belgian Federal minister for energy, Mr. Wathelet, received an approval for his "plan Wathelet" [24] which contains a timeline for the complete phase out of the nuclear capacity. In 2015, the oldest reactors will be closed down and the phase-out will be complete by 2025 [23]. Given the high share of nuclear energy in the Belgian electricity mix, the planned phase-out poses a challenge to electricity producers, regulators and politicians.

Several other aspects complicate this challenge. For example, investments in renewable energy technologies – mainly intermittent technologies – did increase strongly and are expected to increase further between now and 2020. The share of solar PV in total installed capacity in Belgium is among the highest in the EU [9]. Another challenge is the fact that many old thermal assets (coal and gas plants) will also reach their end of life in the coming decades. As a result, about 6000 MW nuclear assets and 4000 MW of thermal assets need to be replaced in 12 years' time [12]. On top of this, the investment climate in the Belgian electricity market depends on the dynamics on the interconnected European electricity markets. Belgium, being a relatively small country in the heart of Western Europe, is strongly impacted by changes in the electricity market in its neighboring countries.

Literature overview

A growing number of studies are focusing on the problem of integrating intermittent renewables in the electricity grid. Eurelectric mentions in their 'Power Statistics and Trends 2012' report that "delivering on renewables will require adapting and developing the entire energy system" [10]. On the operation of fossil fueled back up they state that "the decrease of annual operating hours for conventional plants leads to severe difficulties in covering the cost of generation and removes any incentive for the building of new power plants". Agora [1] published a study on the German 'energiewende' and concludes that the increasing amount of solar and wind energy will radically change the functioning of the electricity market in a couple of years. They claim that base-load power

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Nomenclature

FOD	Federale Overheids Dienst (Belgian Federal Government Service)	LF	load factor
CHP	combined heat and power	FN scenario	Full Nuclear scenario
PV-system	photovoltaic system	NI-capacity	Non-Intermittent Capacity (fossil, hydro, biomass)
BM	biomass	MR	Must Run
IN	intermittent electricity production	D1	Doel 1 (nuclear reactor)
CF	capacity factor	D2	Doel 2 (nuclear reactor)
		T1	Tihange 1 (nuclear reactor)

plants will disappear completely and flexibility will become very important. They advocate a new type of energy market which puts a value on flexibility and on security of supply. Also, activating the demand side is, in their view, very important [1]. A report from OECD's Nuclear Energy Agency also mentions big losses in the profitability of fossil power plants as the share of variable renewables increases. When it comes to nuclear, the report mentions that a reactor start up time of several hours to sometimes days, combined with a low marginal production cost, makes it (economically) impossible for (old) nuclear power plants be operated in a flexible way. Older nuclear plants cannot operate below 50% of their capacity during a prolonged period. New reactors, on the other hand, can be more flexible [20].

Most of the scientific literature focuses on the German 'energiewende'. One paper found the impact of the nuclear phase out in Germany on system costs and electricity prices to be significant, and a substantial transformation of the supply side and demand side would be required to cope with the German Phase out [14]. Another paper concluded that the German phase out would result in an increase in overall greenhouse gas emissions and that the growth of renewables would require an expansion of the transmission capacity [2]. Focusing more on the intermittency issues, Grave et al. [15] found that the rise in wind and PV will have a substantial impact on the full load hours of thermal plants. According to Grave et al. [15], the full load hours for gas plants in Germany could be as low as 2000 (corresponding with a load factor of only 23%) by 2030. The authors conclude that "electricity market design will have to provide incentives to invest into generation capacity which will have low utilization in the future" [15].

These recent studies clearly indicate that the energy landscape in Central West Europe (CWE-region) will change drastically in the next two decades. The combination of a nuclear phase out (in Belgium and Germany) with an increasing amount of renewables and a decreasing profitability of thermal power plants will be very challenging.

Other regions are also confronted with the issue of integrating renewables in a system with nuclear capacity. Zhang et al. [25] have focused on this problem in a Japanese context. They used hourly data on electricity demand in the Japanese region of Kansai, combined with a weather based model for the inflow of PV and wind electricity. The impact of new technologies such as batteries, electric vehicles and heat pumps was also studied. They find that the combination of high shares of PV and nuclear will result in a lot of excess electricity production. However, the introduction of heat pumps, electric vehicles and batteries can to some extent reduce this excess production [25]. A study from Denholm and Hand [5] analyses the impact of variable renewables generation input in various scenarios in Texas (USA) in the ERCOT electricity area. Their data on wind and PV production is based on wind and PV resource maps in the state of Texas. They perform hourly simulations on increasing shares of variable generation (wind and solar energy) in the current ERCOT area. They find that the introduction of high shares of variable generation capacity will increase the need for flexible assets and requires the elimination of the minimum generation constraints imposed by "must run" generation assets. If the penetration of variable generation reaches shares of about 50% of total generation, curtailment of about 5% of the variable assets would be required, depending on the scenario [5].

Contribution to the literature

The above literature overview shows that the problem of integrating variable renewables has become an important issue in recent years. This paper contributes to the existing literature in various ways. Firstly, in this paper we focus on the Belgian situation. The large share of nuclear and the increasing inflow of renewables with priority dispatch will have a huge impact on the operation of the remaining thermal assets in Belgium and the stability of the electricity market in general, already in the next 5 years. Because of the short time scope of the study, we exclude possible future options for grid flexibility such as batteries and electric vehicles. We also exclude the option of constructing new transmission lines, since this requires a lot of time and planning. Secondly, we present a unique methodology, based on 15 min interval data for electricity demand and production from wind turbines and PV-systems. This methodology is different from most papers, which use weather data as a proxy for PV and wind output. In our view, a model based on real, measured output of PV and wind is a contribution to the existing models. Thirdly, in contrast with most papers, we do not use an "optimal" investment or dispatching model. Instead, we look at the current "sub-optimal" situation, where all renewables have priority dispatch and incentives for thermal capacity are virtually absent.

In summary, we compare current and future demand and supply in order to have a better idea on how the increasing share of renewables, combined with the phase out of old nuclear and thermal assets will affect the grid stability and the functioning of the electricity market. To our knowledge, this is the first ever study to quantify on a "% of time" basis the amount of surpluses, shortages and flexible assets' running hours in Belgium. The methodology used here can be applied to other nations as well, especially those with a high share of (intermittent) renewables. We will start by introducing the current situation in Belgium. This will be followed by an elaboration on the model that was used to analyze the shortages, surpluses and number of full load hours for flexible generation. Then, the results will be presented and discussed. Finally we will conclude and provide some policy recommendations.

Methodology

Introduction

In order to interpret the results, it is important to have some insights in the current Belgian situation. In 2013, wind and PV had a share in total installed capacity of 6% and 12% respectively. Nuclear has the highest share in total capacity, closely followed