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Economic curtailment of intermittent renewable energy sources

Arthur Henriot *

Florence School of Regulation, Convento-Via delle Fontanelle, 19, 50014 San Domenico di Fiesole, FI, Italy

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ABSTRACT

In a power system featuring a large share of intermittent renewables and inflexible thermal generators, efficiency gains could be achieved by curtailing the production of renewables. However, as renewables feature very low variable production costs, over-curtailment can be costly. In this article, we use a stylised analytical model to assess this trade-off. We show that while curtailing renewables when their variability is high and the system flexibility is low can reduce generation costs, the different stakeholders will not necessarily benefit from such measures. As a consequence, leaving this decision to generators will lead to a sub-optimal level of curtailment. Either incentives to provide accurate RES availability forecasts or alternatively centralised forecasting should be put into place to solve the resulting problem of asymmetry of information.

1. Introduction

In order to foster the development of renewable energy sources (RES) in Europe, RES benefit from priority of dispatch. Following the European directive 2009/28/EC priority should be given to RES as long as the safety of the power system is not threatened. The curtailment of electricity, i.e. the use of less RES generation than potentially available, should therefore be minimised and should occur only when needed to ensure security of supply.

However, such a priority should be questioned at times when intermittent[1] RES constitute a significant share of the generation mix. The variability of RES and the limited flexibility of the conventional thermal units constitute a challenge for the operation of power systems. This inflexibility is for instance reflected through the occurrence of significantly negative prices (Mayer, 2013; Nicolosi, 2010) in Germany. Such prices reveal that while the variable-cost of electricity generated by RES is equal to zero, releasing the constraints on RES dispatch could still lead to benefits when some generators would be willing to pay to generate (and thus avoid start-up costs or ramp-up constraints). Economic curtailment of RES should then be considered as an additional tool to technical curtailment of RES.[2]

The optimal level of RES curtailment is the result of a trade-off. On the one hand, not using fully "free" (i.e. with a zero marginal-cost) RES energy may result in higher generation costs, as the substitutes are more expensive. On the other hand, it allows releasing part of the binding technical constraints for inflexible thermal power plants. This trade-off is hence impacted by the marginal costs and the flexibility of the thermal power plants, as well as the variability of RES generation. An additional issue is the very different consequences on the stakeholders involved: consumers, thermal power plants, and RES power plants. The level of curtailment maximising the social welfare might result in losses for the stakeholders offering the RES energy. In the absence of compensations, this optimal level of curtailment will then not be reached. The literature on RES curtailment is still in its infancy, and most studies have been focusing on curtailment of RES in order to solve local congestions or to ensure security of supply: curtailment for higher economic efficiency has seldom been studied. Moreover, existing quantitative studies do not deal with variations in the key parameters such as system flexibility or RES variability, and do not assess the impact on each category of stakeholders.

* Tel.: +39 055 4685 713.
E-mail address: arthur.henriot@eui.eu.

[1] The term "variable" is sometimes considered to describe more accurately the nature of RES behaviour. However, the term "intermittent" is commonly employed and will be used in this paper, referring mainly to wind and solar PV technologies.

[2] All along this paper we employ the term "economic curtailment" in opposition to "technical curtailment", i.e. required to ensure safety of operations. It does not mean that technical curtailment has no economic rationale or that economic curtailment is not grounded on technical fundamentals.

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In this article, we build a stylised model of energy production in order to study the mechanisms of RES curtailment for economic reasons. The analysis of the aforementioned trade-off and the consequences on the stakeholders are at the core of our reflection. First, as we want to focus on the efficiency of operations for a given generation mix, our model is a short-term model and the installed capacity of RES and thermal units are exogenous fixed parameters. It is also considered that consumers do not react to prices and that demand for energy is fixed and inelastic to prices. This demand is met by energy supplied by RES generators and thermal generators. Note that the generators do not adopt any strategic behaviour and offer energy at their marginal generation cost. Second, in order to take into account the impact of the variability of production by RES, we consider two successive production time-periods. Availability of RES is stable within each period but can vary significantly between the two periods. Availability of thermal units can also evolve between two periods as units that have not been generating in the first period are limited in the second time-period due to technical ramping or start-up constraints. Third, it is possible to curtail RES generation in the first period. The trade-off is then the one described previously: curtailing RES generation in the first-period leads to higher generation costs in the first-period but allows reducing costs and prices in the second period. Finally, the optimal level of curtailment is established as the one maximising the social welfare, corresponding in this article to the level of curtailment picked by a third party aiming at minimising generation costs across both time-periods.[3] The impact of a given level of curtailment on each category of stakeholders is obtained by measuring the variation of their surplus compared to a situation without any curtailment.

Our results confirm that potential savings will be achieved by adopting an optimal level of curtailment, and we describe the relationship between the key parameters driving these benefits. We then show that depending on the level of RES installed capacity and the system flexibility, the price-impact and the volume-impact of RES curtailment can lead to gains or losses for each stakeholders. Interestingly enough, RES can benefit from curtailment even without compensation. Besides, we argue that if decisions to curtail RES are taken by generators, it will result in sub-optimal level of curtailment. Note that this will be especially the case if thermal generators and RES generators belong to the same utilities. This effect could be mitigated if demand becomes more elastic, which would constitute an interesting extension of this article. At last, the quality and transparency of data on wind availability will be crucial to ensure that efficient decisions are taken, while RES generators will have significant incentives to manipulate these data.

Our paper is organised as follow. We first review the existing literature in Section 2, and highlight the complementarity of our stylised approach with the existing quantitative studies. We then describe in Section 3 the framework of our model and the main assumptions we made. Analytical results are detailed in Section 4, while their policy implications are discussed in Section 5.

2. Previous works

The topic of economic RES curtailment has not been dealt with extensively so far, as the share of intermittent RES in the generation mix was not significant, and priority was given to a fast development of these resources. Helpful contributions focused on the use of market mechanisms to deliver optimal investment and dispatching of wind and solar plants. Ambec and Crampes (2012) for instance showed how the development of these intermittent sources of energy could create a series of issues, challenging the sustainability of the electricity industry without some form of (physical or financial) integration of intermittent and non-intermittent sources. However, Ambec and Crampes do not look at inter-temporal constraints between periods of availability and unavailability. As a consequence, they exclude the possibility of curtailment by setting the output of RES generators (when these resources are available) equal to the installed capacity.

Most existing works on RES curtailment are empirical studies identifying best practices among the curtailment mechanisms put into place worldwide. This is for instance the case of a collection of reports by the National Renewable Energy Laboratory (Fink et al., 2009; Lew et al., 2013; Rogers et al., 2010). These studies highlight the fact that curtailment occurs mainly for technical reasons, when the system encounters transmission or operational constraints. An analysis of different policies for principles of access, including best practices of interruptible connections for wind generation, can also be found in studies by Currie et al. (2011) and Anaya and Pollitt (2013). Yet their focus is the connection of distributed generation at lower costs for network operators. Note that an interesting exception is a study realised for the Public Service Company of Colorado, revealing that curtailing wind to reduce the cycling costs of coal units would lead to significant benefits (Xcel Energy, 2011).

The concept of economic wind curtailment in a context of large-scale integration of electricity from RES is deeply discussed in a qualitative analysis by Brandstätt et al. (2011). Through the example of Germany, they argue that removing the restrictions on RES curtailment will be necessary as the system would otherwise feature too much inflexibility, both on the supply and demand sides. They also present a compensation scheme leading to a reduction of total system costs without deteriorating RES revenues. At last, the authors argue that such a policy would not be conflicting with climate policies, as higher investments in RES would compensate for the curtailed low-carbon energy.

A few quantitative studies can also be found. Ela (2009) argues that curtailing wind generation can be economically advantageous, using the example of a simple three-bus system. Yet, in his model, these benefits result from the existence of congested lines, with wind generation at a given bus preventing the dispatch of cheaper generators. According to Ela, wind generators automatically dispatched have an artificial bid cost that is negative infinite and does not reflect the actual variable cost of generation with intermittent RES. Adjusting these bids to their economic willingness to generate, and curtailing their production when needed, would allow a more efficient management of transmission congestion. In this study, the constraints resulting from the limited flexibility of thermal generators are not taken into account.

Finally, in a recent paper, Wu and Kapuscinski (2013) built a highly detailed power system stochastic optimisation model, and identified a series of efficiency gains thanks to a policy of wind curtailment. They show that the flexibility provided by curtailing RES allows the use of cheap and inflexible thermal units instead of more expensive flexible thermal units. The major components of the savings identified by Wu and Kapuscinski result from avoided cycling costs. According to their study, by curtailing intermittent RES, it is not only possible to lower operation costs but it is also possible to achieve system emission reductions.

Despite these quantitative studies, we believe there is room for further investigation. A limit of the existing numerical quantitative studies is that key parameters such as the system flexibility or the variability of RES are either not considered or set to a single value. Hence, the first significant contribution of our approach based on a stylised model is that we are able to describe the relationship between pivotal parameters (flexibility, variability, and installed capacity of RES) and the optimal level of curtailment. By using a tailor-made stylised model we are able to focus on optimal curtailment policy for different values of these parameters. Moreover existing works only assess the variations of overall

[3] Social welfare can include many other aspects that are not taken into consideration in this analysis. Externalities related to carbon emissions are for instance considered to be internalised into generation costs. Aspects related to security of supply are neglected in this short-term perspective.