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The economic impact of electricity losses

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ABSTRACT

Although electricity losses constitute an important, but inevitable, amount of wasted resources (and a portion that has to be funded), they remain one of the lesser known components of an electricity system, and this despite the fact that the decisions of generators, transmission and distribution system operators and consumers all impact on them. In this paper we analyse the effects of such losses from two perspectives: from that of consumption and from that of generation.

Given that end-user consumption varies across the day, consumption has direct implications for electricity losses. Indeed, demand-side management policies seek to encourage consumers to use less energy during peak hours and to reduce network congestion. At the same time, from the perspective of generation, the recent growth in distributed generation has modified the traditional, unidirectional, downward flows in electricity systems. This affects losses as energy is produced in the lower voltage network, which is closer to points of consumption.

In this paper we evaluate the impact of consumption patterns and different generation technologies on the energy losses and the cost of losses. To do so, we draw on data from a real electricity system with a high level of renewable penetration, namely, that of Spain between 2011 and 2013. To the best of our knowledge, this is the first paper to analyse the real impact of consumption and the effect of each generation technology on energy losses, offering an opportunity to evaluate the potential benefits of demand-side management policies and distributed generation. Losses are divided between transmission and distribution levels, which is also a novelty that allows us to better define our regulatory recommendations aimed at exploiting to the full these potential benefits. Our results should serve as a baseline for countries at the early stages of implementing these policies.

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1. Introduction

Electricity networks serve to transport energy to consumption points, as generation plants are not always sited close to homes and industries. To guarantee the success of the system, four essential activities have to be successfully managed: generation, transmission, distribution and retailing. Traditionally, electricity is generated in large-scale plants located near raw materials, or reservoirs in the case of Hydropower. Economies of scale are critical at the generation stage before the energy can be sent to points of consumption via a transmission network comprising high-voltage lines. In recent years, a number of new, small generation plants have been connected to the distribution grid, and this is known as distributed generation (DG) (Ackermann et al., 2001). To distribute the electricity among consumers, low-voltage (LV) distribution lines are used to transport power to meters. Finally, retailing is responsible for billing.

Owing to certain physical phenomena, electricity systems always yield less than 100%, with some energy being lost as it flows through the components of the system: lines, electric transformers, etc. This means that when a consumer i wants to consume q_i units of energy (UoE) as recorded by their meter, $(q_i + \delta_i)$ UoE have to be produced by a generation plant, given that δ_i UoE are lost in the grids. In the aggregate, Q represents total meter consumption (Eq. (1)) and Q_L is the meter consumption with the energy losses incurred (Eq. (2)):

$$Q = \sum_i q_i \tag{1}$$

$$Q_L = \sum_i (q_i + \delta_i) = \sum_i q_{il} \tag{2}$$

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Cross-country comparisons of electrical energy losses are far from straightforward, because, among other reasons, regulatory definitions vary; consumption out of the meter, or fraud, may or may not be considered as an energy loss. Different voltage levels are used by transmission system operators (TSOs) and distribution system operators (DSOs) (ERGEG, 2008). Energy losses in Spain in 2012 represented 8.9% of the total energy injected into the grid, resulting in an annual cost of 1,160 M€[1] that had to be borne by all consumers. This increases their final electricity bills, decreases consumer surplus and impacts on social welfare. These effects are the main motivation for further exploring the economic impact of energy losses through this empirical analysis. To put this figure in context, total energy loss levels published in the World Bank Database[2] for other countries in the same year were 7.92% in the United Kingdom, 3.94% in Germany, 6.74% in France, 5.4% in Austria, 6.29% in the United States of America and 5.06% in Australia.

The mechanism by which energy losses affect the retail price is illustrated in Fig. 1. First, based on the characteristics of the formation of the electricity wholesale price (WP), energy losses exert an upward pressure on total demand, so that the D curve is displaced upwards to D_L. Second, real hourly demand might differ from that estimated on the day-ahead wholesale market, which means additional adjustment costs are incurred. Third, when the cost of losses is totally or partially borne by the end-users, three possible mechanisms can be applied to fund them: the regular network tariff, as in France, Sweden, Norway, a special tariff, as in Austria, Poland, or other specific mechanisms as in Italy, Portugal, United Kingdom and Spain (ERGEG, 2008). In the end, regardless of the mechanism, when the cost of losses is borne by the end-users, the amount they pay ($q_{il} \cdot p_{il}$) and the consumer surplus are both affected (ENTSO-E, 2014). In the period 2011–2013, the cost of losses in Spain represented between 1.47 and 5.19% of the retail price of electricity[3].

The implementation of policies that modify electricity flows, on the demand and supply side, could have an impact on energy losses. In Spain, as in other European countries, they include, for example, the massive introduction of intelligent meter systems, or smart meters, to promote the active participation of consumers in the electricity supply market via the use of innovative pricing formulas and the promotion of electricity generation from renewable energy sources (RES-E), which in most cases has been implemented in conjunction with a priority dispatch for generation from promoted technologies (European Directive 2009/72/EC).

On the demand side, the impact of consumers on energy losses is unequal, depending on the voltage of the network to which consumers are connected and how peaked their demand profile is (Shaw et al., 2009). DSOs must play a passive role regarding consumers since the unbundling of activities (European Directive 1996/92/EC), while the possibilities of modifying peak demand profiles depend on specific technological solutions, such as smart meters, which can provide consumers with clearer price signals that might in turn modify their behaviour. Along these lines, European Directive 2012/27/EC requires network tariffs and regulation improvements to support dynamic pricing for demand response by final consumers, such as time-of-use tariffs, critical peak-pricing, real-time pricing and peak time rebates.

On the supply side, and in response to the 2020 European Strategy, the share of energy produced by RES-E in Europe (EU28) has increased from 14.32% in 2004 to 25.37% in 2013. This change has been accompanied by the installation of new small RES-E plants known as DG connected directly to DSO networks and located close to the points of consumption. This has had a significant impact on most electricity systems. For instance, in Spain, a quarter of the country's total generation between 2011 and 2013 was produced directly by plants connected to this network. These changes have modified traditional unidirectional flows from transmission to distribution, and some technical and operational problems have arisen in relation to their geographical dispersion, predictability, the flexibility of the remaining generation, the correlation between production and consumption profiles, and the extent to which the network can absorb the imbalances between them.

Although intuition tells us that a higher share of generation in close proximity to consumers would reduce energy losses and grid congestion, as the energy would have to travel over shorter distances, DG plants are not always properly sited close to the main points of consumption, their production is not always dispatchable[4] and the smaller plants are often operated and fully controlled by their owners (Eurelectric, 2013a). As a result, DG production might not coincide with demand requirements. A number of authors, including Quezada et al. (2006) and Marinopoulos et al. (2011), report that energy losses follow a U-shape curve as a function of the DG penetration in the networks,[5] which means they tend to fall at low levels of DG capacity, but increase after a given level is reached. The Spanish regulatory framework[6] provides for the free location of electricity generation, which has resulted in the heterogeneous establishment of DG capacity throughout the country's grid.

The potential consequences, both problems and benefits, to be derived from the active participation of consumers through smart meters and the widespread penetration of DG have called the current DSO regulatory framework into question. In this regard, CEER (2015) proposes various ideas that need to be considered in the future. For example, in the case of consumption and smart meters, future tariffs should encourage consumers to reduce peak demand thereby increasing the efficiency of electricity systems. Moreover, tariffs should give clear economic signals, enable DSOs to recover their costs and be compatible with retail competition. In the case of generation, DG has increased the complexity of flows in the distribution grids and with them the challenges for their efficient management. Hence an evolution has been proposed of the relationship between the TSO and the DSO that adopts some principles: a whole system approach, greater coordination and exchange of data, more flexibility and a fairer cost sharing strategy. Moreover as interaction between, and communication with, consumers and producers increases the DSOs should arrange new activities and take on new responsibilities. Here, smart grid investments seem to represent a key facilitator (Farhangi, 2010; Joskow, 2012).

To the best of our knowledge, most papers that have analyzed electricity grids up to now are based on Optimal Power Flow (OPF) algorithms from engineering and no previous studies have empirically and separately assessed (ex-post) the determinants of the energy losses from transmission and distribution grids from the demand and supply side in a whole country with a real electricity system, and with an economic approach. This is a novel approach to

[1] Following the Spanish Regulatory Framework (see Section 3.2), the annual cost of losses is calculated by multiplying the amount of hourly energy losses (MWh) by the hourly wholesale price of electricity (€/MWh). Both costs of losses in the transmission and distribution grid level are quantified at the same -wholesale- price (€/MWh) and included in the consumer bills. The costs of CO_2 emissions and energy savings targets are not included in these calculations.

[2] Source: World Bank Database - *Electric power transmission and distribution losses (% of output).* http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS (last consulted on 15 September, 2015).

[3] These are average costs and vary with the level of voltage, where consumers are connected and the tariff scheme being implemented. In general, the lowest costs are associated with the heaviest consumers connected to the highest voltage grids.

[4] *Dispatchable sources* are technologies the output of which can be adjusted or turned on/off on request. This is not the case of photovoltaic systems, where for a third of the day they do not produce, or small wind plants.

[5] *Level of DG penetration in a network* is the amount of energy generated by DG in an area in relation to total consumption.

[6] Royal Decree 54/1997.

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