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Energy Sustainability

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Postal Address:
Chair in Energy Sustainability
Institut d'Economia de Barcelona
Facultat d'Economia i Empresa
Universitat de Barcelona
C/John M Keynes, 1-11
(08034) Barcelona, Spain
Tel.: + 34 93 403 46 46
ieb@ub.edu
http://www.ieb.ub.edu

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ABSTRACT: Worldwide, countries are implementing policies to develop greener energy markets. In Europe, the ¨2030 Energy and Climate Package¨ asks for further reductions of GHG, renewable sources integration, and energy efficiency targets. These objectives may counterbalance each other modifying the electricity flows, and hence, affecting the electricity losses. Precisely, the extra amount of energy necessary to cover losses is the departure point from which we analyze the impact of losses on CO2 emissions. With this purpose we use Spanish market and system data with hourly frequency from 2011 to 2013. Our results show that electricity losses significantly explain CO2 emissions, with higher CO2 emissions when covering losses that those on the average system. Additionally, we find that the market closing technologies used to cover losses have positive and significant impacts on CO2 emissions: when polluting technologies (coal or combined cycle) close the market, the impact of losses on CO2 emissions is greater in comparison with the rest of technologies (CHP, renewables or hydropower). From these results we make some policy recommendations to reduce the impact of losses on CO2 emissions.

JEL Codes: L11, Q40, Q50, Q54

Keywords: Electricity losses; CO2 Emissions; Electricity markets; Renewable energy

Daniel Daví-Arderius
University of Barcelona &
Chair of Energy Sustainability, IEB
E-mail address: daniel_davi@yahoo.es

María-Eugenia Sanin
Université d´Evry Val d´Essonne &
Ecole Polytechnique
E-mail address:

Elisa Trujillo-Baute
University of Warrick &
Chair of Energy Sustainability, IEB
E-mail address: elisamtrujillob@gmail.com

1. INTRODUCTION

According to IPCC estimations, the power sector has the highest contribution to greenhouse gases (GHGs): 25% emissions were related to the electricity and the heat production in 2010[1]. Indeed, most regulatory efforts in terms of emission reduction around the world are mainly focused in power generation[2]. In Europe, 1,453 combined heat and power (CHP) generation plants have participated in the European Union Emission Trading Scheme (EU ETS), which is the regulatory instrument that was settled by the European Commission (EC) in 2005 to cap CO2 emissions in line with the Kyoto Protocol targets (Berghmans and Alberola, 2013). In October 2014, the “2030 Energy and Climate Package” has pushed forward the clean generation incentives by 2030: 40% cut in GHG emissions, 27% of energy from renewable sources and 27% improvement in energy efficiency[3].

As stated by Guivarch and Monjon (2016), a low-carbon future world compromises energy security in Europe and is related to uncertainty regarding new technologies, fossil fuel resources, markets and economic growth. In fact, electricity systems are undergoing significant changes, mainly due to: the penetration of new renewable sources of electricity (RES-E) in the generation mix; the introduction of the information and communications technology (ICT) to monitor and grid control; the wide installation of smart meters at end-consumers, which empowers them through the implementation of demand side management (DSM) policies; and the electric vehicle (EV).

The incentives implemented in most European countries to promote RES-E are helping replace the traditional most polluting technologies (coal and fuel) by new zero-CO2 emission generation plants: solar, wind, geothermal, etc. This has been accompanied by the wide-connection of numerous small generation plants or distributed generation (DG). The significant DG penetration has modified the traditional top-down energy flows (Ackermann et al., 2001)[4]. All the aforementioned changes may modify the electricity flows and have an impact on losses, which represents an extra amount of wasted energy that must be generated in the electricity systems affecting economic efficiency.

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[1] See IPCC 2014 report at http://mitigation2014.org/report/summary-for-policy-makers.
[2] See for example the recent North American efforts: RGGI and California-Quebec.
[3] This Packaged is the ambitious development of its predecessor, the “2020 Energy and Climate package” enacted in 2009 by the EC pledging for: 20% cut in GHG emissions, 20% of energy from RES-E and 20% improvement in energy efficiency.
[4] It is important to note that not all RES-E plants are considered DG because some are also large plants directly connected to the transmission system operator (TSO) networks.

Recent literature on losses has mainly focused on the analysis of demand (DSM) and supply policies (DG/RES-E). On the one side, DSM calls on various techniques to obtain a better performance of the infrastructure, reduce the congestion problems, adapt demand to the capacity of generation at each moment in time, and reduce losses (Strbac, 2008). The slightly small potential impacts of DSM on the loss reduction are shown by Shaw et al. (2009) and Costa-Campi et. al (2016).

On the other side, the impact of DG on losses is based in their location, operation and hourly production. The decarbonisation of the electricity sector involves reconfiguring spatial patterns and potential changes in the location of the key energy system components (Bridge et al., 2013). Indeed, an argument to justify DG is that losses related to their use are expected to be lower because the distance to consumers is also lower. However, given that losses follow a U-shape trajectory with the degree of penetration of DG (Quezada et al., 2006 and Delfanti et al., 2013), unwanted effects might counterbalance their potential benefits. This trade-off was empirically proved in the Spanish case, where solar and wind perform better in terms of losses than the rest of traditional technologies, but the opposite is true for CHP since its production profile is quite flat and not well correlated with demand (Costa-Campi et. al., 2016).

In relation to the CO2 impact of electricity power systems, numerous papers have made contributions in different directions. Ummel (2012) calculates the CO2 impact of electricity production by plant worldwide giving birth to the CARMA database[5], Marriot et al. (2010) simulate CO2 scenarios using alternative energy mixes in the U.S. and Feng et al. (2009) estimate the CO2 content of regional energy consumption in China. More recently, the attention has shifted to the air pollution avoided due to renewable installation and the evaluation of the subsidy costs with respect the social pollutant benefits Using data from the ERCOT market in Texas Novan (2015) introduces the analysis of the external benefits due to renewables, which consists on the avoided CO2 emissions related to each technology when the time of production and the whole generation mix are considered. He states that renewable subsidies should provide more financial support to investments that provide larger external benefits on the pollution, instead of the current homogeneous policies (see also Cullen. 2013, and Kaffine et al., 2013). Finally, the papers closest to ours are the ones that consider the CO2 impact of the system efficiency. This is the case of Amor et al. (2014) that documents the impact of congestion on CO2 emissions and Stoll et al. (2014) that study the impact of DSM

[5] See http://www.carma.org.

policies by calculating an hourly CO2 signal applied to the hourly electricity market data in Great Britain, Ontario and Sweden. They find that load shifts from high-price hours, which result in mix-generation carbon emission reductions, specially where price and CO2 intensity are positively correlated.

The previous literature review underlines the contrasted impact that electricity market design has on CO2 emissions. Additionally, a stylized fact in electricity markets is that, when extra generation is needed, fossil fuels are often used on account of their flexibility (in the absence of storage possibilities) increasing the CO2 content of the energy mix. That extra generation may also be needed due to positive shocks in demand, congestion or losses in the grids. To the best of our knowledge, the impact of electricity losses in CO2 emissions has not been studied yet, which is our objective here. The paper closest to our argument is Lindner, et al. (2013), where they compare the CO2 content of generation versus consumption among different regions in China. Hydroelectric plants are sited in the southwest, coal plants (60% of CO2 Chinese emissions in 2010) in the north and northwest, while the growing electricity demand is in the eastern coast. They use a bottom-up model to quantify the emissions embodied in the inter-provincial flows, and find a shift of environmental pollution away from economically well-off provinces to resource-rich, and less developed provinces. Although their study highlights regional flows, they do not consider losses as a parameter in their estimations, which is also presumably significant in terms of CO2 impact. Our approach is different because we study the country as a whole to focus on the understanding of the relation between losses and the system CO2 emissions.

Our paper contributes to the evaluation of the energy and climate policy imposed on the power sector. In particular, we assess the CO2 impact that changes in the energy flows may have through losses. With this purpose, we empirically estimate the CO2 content of power generation as a function of the transmission and distribution losses using Spanish hourly data from 2011 to 2013. We consider Spain because, among the five biggest economies of Europe, it had the highest share of energy generated by RES-E in 2013 (36.39%) and its level of losses are in the average range for European countries[6]. From 2004 to 2013, the five biggest economies in Europe increased their RES-E share of energy production from 9.40 to 25.59% in Germany, 3.54 to 13.85% in the UK, 13.79 to 16.87% in France, 16.09 to 31.30% in Italy, and 18.98 to 36.39% in Spain. Indeed,

[6] Source: Eurostat Database - Short Assessment of Renewable Energy Sources (% of electricity generation from all sources): http://ec.europa.eu/eurostat/web/energy/data/shares (last consulted on 24 September, 2015).

according to our calculations, energy losses in Spain represented the 8.90% of the amount of energy injected in the grids (2012), which represented an annual cost of 1,160M€[7] that is borne by all consumers. According to the World Bank Database[8] other European countries like Portugal and United Kingdom are in a close range with 10% and 8% losses, respectively, while the extreme high rank cases are Croatia and Lithuania with 18% and 19% of losses, respectively. Our results will not only be useful for Spain, but they will be a key point of reference for countries that are in an earlier stage in the implementation of these policies with similar levels of RES-E penetration and/or similar or higher system losses.

The rest of this article is organized as follows. In Section 2 we describe the data used emphasizing on the relationship between system losses and CO2 emissions. Section 3 includes the empirical test on the system losses contribution to the system CO2 emissions, while conclusions and policy implications are explained in Section 4.

2. DATA DESCRIPTION

In this section we present detail description of the hourly data over the three years' period (2011-2013) used to perform the empirical analysis on the impact of losses on CO2 emissions. We start by informing on our endogenous variable: the system total CO2 emissions. This is followed by an apprise on the explicative variable of main interest, the system losses, and on the additional controls. Finally, we provide detail information on the technologies operating at the margin of the market, as the key element defining the nature of the relation between the system CO2 emissions and losses.

The endogenous variable in our models is the hourly total CO2 emissions in the system $(CO_2 Tot_t)$, calculated from the hourly generation by technology and the Spanish conversion factors. Data on the generation by technology (in MWh) is obtained from Spanish system operator (SO; see REE, 2014) and the data on conversion factors is published by the Spanish Ministry of Energy[9] (in CO2 Tons per MWh with values for 2011). The conversion factors are equal to 1 for coal, 0.74 for fossil fuels, 0.41 for CHP

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[7] Annual cost of losses by the multiplying hourly losses (MWh) by the electricity hourly Price (€/MWh). See Costa-Campi et al. (2016) for further details.

[8] Source: World Bank Database - Electric power transmission and distribution losses (% of output). http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS (last consulted on 6 June, 2016).

[9] More precisely, the emission factors are computed by the Institute for Energy Diversification and Saving (IDEA), ascribed to the Ministry of Industry, Energy and Tourism (information obtained from http://www.idae.es/index.php/lang.uk last consulted on 30 September, 2015).

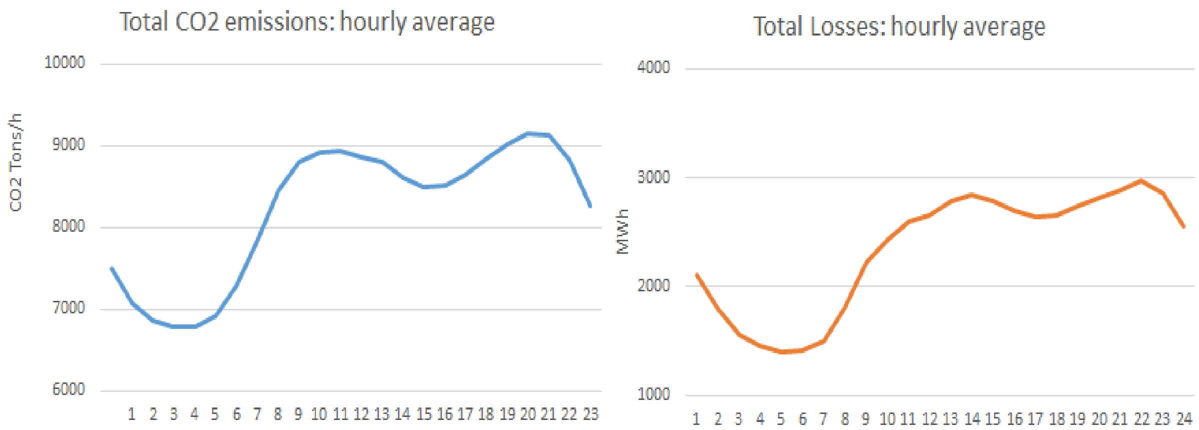
and 0.38 for combined cycle. Although marginal emission rates vary according to the range of production of the plants, we are considering them constant by technology, as other authors do in the literature (see Noval, 2015). On average, during the period considered, the energy mix included more than 33% from this pollutant technologies, and the system content more than 8,220 CO2 Tons/h. Considering the average load of 30,785.76 MWh, on average in the Spanish system around 0.27 Tons/h of CO2 are emitted per each MWh of energy consumed.

In Spain, the electricity grids with a voltage higher than or equal to 220kV are considered transmission and are owned and operated by the Spanish TSO (Red Eléctrica de España, REE), while the rest are considered distribution and is owned and operated by the distribution system operators (DSOs). Methodologically, hourly losses at each level are calculated as the difference between the sum of energy injected by all generation plants and all energy withdrawn for consumers measured at their meters. In this article we use the sum of both losses in the transmission and the distribution levels to perform our estimations since we consider the electricity system as a whole. Our geographical area excludes Balearic and Canary Islands, because their specific characteristics could bias our results. Data used is published in the monthly settlement reports of the Spanish SO[10], where there is hourly information from generators, TSO, DSOs and consumers, (see REE, 2014).

The resultant average hourly losses (L_t) and total CO2 emissions in the system ($CO_2 Tot_t$) are shown in Figure 1. It is apparent that both variables follow a similar pattern, and precisely here is the focus of our analysis. As we will latter argue, the similarity on the series pattern may be explained by the use of pollutant generation as closing technologies in the peak hours. In addition, the daily averages of total CO2 emissions, presented in Table 1, shows important within the week variations in the series. These hourly and daily patterns call to control for load ($Load_t$) and seasonality (day of the week, DOW_t) when we analyse the impact of losses (L_t) on CO2 emissions in the Section 3.

[10] We use the last settlement report for each month (C5), which is the most definitive. However, in May 2011 we use the C6 because it is also available.

Figure 1. Average hourly CO2 emissions ($CO2Tot_t$) and losses (L_t).



Source: own elaboration.

Table 1. Average hourly CO2 emissions ($CO2Tot_t$) by day of the week.

Monday	Tuesday	Wedn.	Thurs.	Friday	Saturday	Sunday	Average
8,333	9,058	9,136	9,046	8,829	7,130	6,026	8,223

Source: own elaboration.

With the data described we perform a first test on the impact of electricity losses on the system CO2 emission. However, in order to obtain a superior insight of the nature of this relation, we get a closer look to what happens at the margin of the market.

As in most of the liberalized energy only markets, generation plants bid their production in the wholesale market at their marginal cost in an ascending order. The more expensive -usually dispatchable- technologies[11] close the market. The integration of RES-E is causing important changes in the hourly market of electricity. On one side, weather conditions are quite random (wind, hydropower, etc.), and this implies the requirement of backup technologies. On the other side, not all the RES-E technologies are dispatchable, and in most cases they are implemented in conjunction with a priority dispatch over the rest of technologies (European Directive 2009/72/EC). These factors represent a major challenge in balancing generation with consumption, whose peak demand does not match their production[12]. Both, random weather conditions and priority of dispatch also affect the market and operation of the traditional dispatchable fossil-fired plants (coal and combined cycle) with their correspondent CO2 emissions uses to cover

[11] *Dispatchable technologies* are ones that can be regulated to match changes in demand and/or system requirements and which can be turned on and off based on their economic attractiveness (Eurelectric, 2011).
[12] For instance, in Spain the solar production is not able to cover the peak-noon consumption at 9pm.

peak (Eurelectric, 2011). In this context, to better understand how the extra amount of energy required to cover losses is affecting the system CO2 emissions, is therefore necessary to look at the technologies used to cover losses, the marginal technologies - closing the market.

Data on the technologies closing the market each hour ($Tech_{it}$) is published by the Spanish market operator (OMIE)[13]. To unequivocally associate losses with specific technologies, we focus on the hours where a single technology closes alone. During the period considered here, in 70% of the hours a single technology closes alone, being hydropower the most frequent with 30.3% of the hours and this is followed by coal with 25.5% of hours. The least frequent ones are combined cycle that closes alone only in 10.2% of hours, and Special Regime[14] that close alone in 2.9% of hours. We will include this information in our model as dummy variables, which are equal to one when the correspondent technology closes alone (CO_t for coal, CC_t for combined cycle, SR_t for Special Regime, and H_t for hydropower), and cero othrwise. Table 2 provides full summary statistics of the variables we use to perform our empirical analysis presented in the next section.

Table 2. Summary Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
CO_2Tot_t	26,304	8220.52	2895.08	1903.46	16339.99
L_t	26,304	2,339.97	645.77	972.03	4,289.70
$Load_t$	26,304	30,785.76	4,669.14	20,319.16	46,124.55
DOW_t	26,304	2.997263	2.001632	0	6
CO_t	26,304	0.255	0.436	0.000	1.000
CC_t	26,304	0.102	0.303	0.000	1.000
SR_t	26,304	0.029	0.169	0.000	1.000
H_t	26,304	0.303	0.459	0.000	1.000

Source: own elaboration.

[13] OMIE considers a technology to be closing at each hour if it is matching with and generating at least 5% of the generation in that hour.

[14] In Spain, generation technologies were classified into Ordinary and Special Regime, which includes only the subsidized technologies: RES-E (photovoltaic, solar thermal, geothermal, wind, etc.) and combined heat and power (CHP).

3. EMPIRICAL TEST ON THE LOSSES CONTRIBUTION TO CO2 EMISSIONS

Before presenting the time series regression models constructed for the analysis of the impact of system losses in total CO2 emissions, it should be pointed out that a stationary time series analysis was carried out. We performed two tests. First, the augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) under the null hypothesis of a unit root, and second the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests (Kwiatkowski, et al., 1992) under the null hypothesis of stationarity. Both tests, reported in Table 3, confirm that the series are stationary in levels, so we estimate the models using all series in levels.

Table 3. ADF and KPSS tests with variables in levels

	ADF test	KPSS test
CO_2Tot_t	-27.382***	0.086
L_t	-80.107***	0.053
$Load_t$	-64.892***	0.075

Note: Test results are statistics. The Modified Akanke Information Criterion determines lag length. The trend was not significant in any case, and hence, it was excluded. ADF null hypothesis of unit root. KPSS null hypothesis of stationarity. *** Significant at 1%

Herein we present the outcomes of our empirical evaluation on the impact of losses on the system total CO2 emissions. Firstly, we estimate the system CO2 emissions as a function of losses to assess whether there is a significant effect and, secondly, we estimate to which extent the previous result depends on the market closing technology as these are providing the extra generation required to cover losses. Our methodological choice it is based on the principle of simplicity, and given that the variables are stationarity in levels, a simple regression model using OLS method is sufficient to perform the analysis.

3.1. ARE LOSSES CONTRIBUTING TO THE CO2 EMISSIONS?

We study whether losses are significant to explain in total CO2 emissions by estimating equation (1), which captures the effects of losses (L_t) on total CO2 emissions ($CO2Tot_t$), controlling for the system load ($Load_t$) and seasonality patterns for the day of the week (DOW_t):

$$CO2Tot_t = \alpha_0 L_t + \alpha_1 Load_t + \alpha_2 DOW_t + \varepsilon_t \quad (1)$$

Results from estimations of equation (1) are shown in Table 4, where each column represents a different outcome according to the variables and seasonality included. Indeed, they show that electricity losses (L_t) explain CO2 emissions ($CO2Tot_t$) significantly. Considering the column (4) outcome, where both seasonality (DOW_t) and load ($Load_t$) are included, results show that on average for each MWh of electricity generated to cover losses 1.002 Tons/h of CO2 are emitted in the system. When comparing this result with average emission of 0.27 CO2 Tons/h per MWh of power in the system, it is apparent that losses not only contributes to the system emissions, but that the extra amount of energy required for losses is of great importance in the total system CO2 emissions.

Table 4. Effect of losses on total CO2 emissions.

	(1)	(2)	(3)	(4)
L_t	3.420***	0.630***	2.540***	1.002***
	(0.0067)	(0.0439)	(0.0153)	(0.0439)
$Load_t$		0.220***		0.147***
		(0.0034)		(0.0039)
Seasonality	N	N	Y	Y
Observations	26,304	26,304	26,304	26,304
R-squared	0.907	0.920	0.921	0.925

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

3.2. EMISSION´S CONTRIBUTION OF THE TECHNOLOGY USED TO COVER LOSSES

Once confirmed that losses have a significant impact on the system CO2 emission, we evaluate to what extent this effect may be explained by the use of pollutant generation as closing technologies. To that purpose we modified the model represented in equation (1) as is now described in equation (2). Accordingly, the effect that each technology has on the system CO2 emission ($CO2Tot_t$) is isolated through the inclusion of an interaction between the losses (L_t) and the technology closing alone each hour ($Tech_{it}$).

$$CO2Tot_t = \alpha_0 L_t + \alpha_1 \ L_t \cdot Tech_{it} + \alpha_2 Load_t + \alpha_3 DOW_t + \varepsilon_t \quad (2)$$

With $Tech_{it}$ as the set of four dummy variables CO_t; CC_t; H_t; SR_t which are equal to one when the correspondent technology closes alone: CO_t for coal, CC_t for combined cycle, H_t for hydropower, and SR_t for Special Regime. Results of equation (2) estimations, capturing the effect from losses covered by each technology, are presented in Table 5.

Table 4. Effect of losses and closing technologies on total CO2 emissions

	(1)	(2)	(3)	(4)
L_t	1.025***	1.006***	1.044***	0.998***
	(0.0436)	(0.0439)	(0.0448)	(0.0440)
$Load_t$	0.139***	0.145***	0.145***	0.147***
	(0.0039)	(0.0039)	(0.0039)	(0.0039)
$CO_t * L_t$	0.293***			
	(0.0145)			
$CC_t * L_t$		0.222***		
		(0.0210)		
$H_t * L_t$			-0.0610***	
			(0.0130)	
$SR_t * L_t$				-0.108***
				(0.0393)
Seasonality	Y	Y	Y	Y
Observations	26,304	26,304	26,304	26,304
R-squared	0.926	0.925	0.925	0.925

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Since we focus on the hours when a technology closes alone, we individually estimate the effects that each technology has on the total CO2 emissions. From the results obtained it is observable that polluting technologies (columns 1 and 2) have a positive and significant effect while SR[15] and H (columns 3 and 4) have a significant and negative effect.

By looking at the sum between the estimated parameters for losses and each interaction term, it is possible to calculate the contribution of losses to CO2 emissions when each particular technology is matching the market and most likely covering losses. In

[15] As was explained in Section 2, SR includes both RES-E and CHP.

particular, 1.32 Tons/h of CO_2 are emitted in average for each MWh of energy generated to cover losses when coal is the marginal technology (column 1). Likewise, when combined cycle is closing alone, 1.23 Tons/h CO_2 are emitted in average for each MWh of energy generated to cover losses (column 2). Finally, 0.98 Tons/h CO_2 (column 3) and 0.89 Tons/h CO_2 (column 4) are emitted in average for each MWh of energy generated to cover losses when hydropower and special regime, respectively, are the marginal technologies.

When comparing the results from theses technology-specific estimations with the average effect of losses obtained from the estimation of equation (1) it is evident that, when coal and combined cycle are the closing technologies the contribution of losses to CO_2 emission is higher than the average (1.002 Tons/h CO_2), while when the closing technologies are hydropower or special regime the opposite is true. The case of coal it is particularly concerning because when this technology is closing, in average, for each MWh of energy generated to cover losses 1.32 Tons/h of CO_2 are emitted, while the average level of emissions in the system is 0.27 Tons/h per MWh. Finally, weighing one thing against another, when coal is the single technology closing the market, for each MWh of energy generated to cover losses the effect on CO_2 emissions is 48% higher than when the single closing technology is part of the special regime.

The previous results complement the findings of Novan (2015): we find that important differences in the CO_2 impact of losses arise when we take into account which has been the technologies used to cover them. Considering that part of the reason for those losses is the distant location between generation facilities and consumption, losses might represent an additional variable to include in what Novan calls the ‘heterogeneous external benefits’ related to each renewable technology.

4. CONCLUDING REMARKS AND POLICY IMPLICATIONS

Electricity systems have been transformed during the last years with the aim to improve energy security, efficiency and pollution reduction, in particular Green House Gases due to the generation mix. Up to now, electricity losses have mostly been considered a matter of efficiency for regulators, or as an economical cost for consumers. However, in this paper we take a step further and contribute to this debate by estimating empirically the impact that losses have on CO_2 emissions.

Our results show that losses significantly explain CO2 emissions with a contribution superior to the average emissions in the system, and that the closing technology used to cover those losses is particularly relevant. Indeed, when coal or combined cycle closes the market (alone), there is a significant and positive effect on the CO2 emissions due to losses, while when special regime or hydropower are the closing technologies the impact is significant but negative. From these results we conclude that the polluting impact of losses is important and should be taken into account in the future market design.

The policy implications derived from the previous results can be classified into two main groups: policies devoted to reduce the amount of losses and policies focused on the reduction of the CO2 emissions of the extra generation necessary to cover losses.

Regarding the amount of losses, the implementation of distributed generation near consumption goes in the right direction. Demand side management policies, which aim to reduce demand at peak periods through hourly prices of electricity, are another possibility to reduce losses by means of reducing grid congestion. Unfortunately, the impact of demand side management on losses is small (Shaw et al., 2009; Costa-Campi et al, 2016). A complementary possibility to reduce losses is implementing energy efficiency measures since losses are proportional to demand.

Regarding the reduction of CO2 emissions, the penetration of RES-E is replacing the electricity generation from traditional pollutant plants. However, the wide-connection of RES-E plants is increasing the short-run variability of the whole generation mix, which has pros and cons depending on which (complementary) solution is applied to match the random generation capacity and consumption. The use of the traditional pollutant technologies (e.g. coal or combined cycle) as back up plants is the most used solution up to now, but has a severe impact on CO2 emissions, as shown in this paper. The closure of the most polluting coal plants and their replacement by combined cycle is an intermediate step. Storage and transborder capacity could be alternatives to offset the RES-E variability but both of them have advantages and disadvantages, in particular in terms of costs, that must be considered as well.

Finally, our results also highlight that subsidies schemes for renewables should also consider the individual external benefits on CO2 emissions in order to get the best potential of them, in line with Novan`s (2015) results. Up to now, generation incentives have mostly considered the quantity of RES-E installed capacity over their locations and individual offsets in CO_2 emissions.

In summary, electricity systems are very complex and there are several complementary policies to reduce CO_2 emissions. The success of this path will depend on a deep understanding of its operation, features, and how to manage the equilibrium between them. This paper could be extended to study the impact on CO_2 through losses of the location of different RES-E installations.

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