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The driving factors of CO_2 emissions from electricity generation in Spain: A decomposition analysis

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Abstract

We apply an index decomposition analysis to investigate the main drivers of CO_2 emissions in the electricity generation sector in Spain over the period 1991–2017. The analysis allows us to quantify the impact of five different effects —associated with an extended version of the Kaya identity— that influence those emission trends. These effects are: the carbonisation effect, the transformation effect, the fossil intensity effect, the electricity intensity effect and the production effect. Taking into account the evolution of these emissions over the period, four subperiods are identified. The results show that the relevance of the drivers has changed over time (i.e. in the four subperiods). The fossil intensity, electricity intensity and production effects played an important role in the increase in emissions during the first half of the period, and particularly from 1999 to 2005. In contrast, the carbonisation and fossil intensity effects were the dominant drivers of the reduction in emissions between 2006 and 2010. The research allows the impact of different measures on emissions to be evaluated by considering their influence on the different effects, and suggests which sets of measures would be more effective in reducing emissions. Therefore, several policy implications are derived.

Keywords: CO_2 emissions; electricity generation; logarithmic mean Divisia index.

1. Introduction

Greenhouse gas emissions in Spain increased well above what was agreed in the Kyoto Protocol during the period 1990–2012, in such a way that it was only after disbursing more than 800 million euros in the purchase of rights that Spain was able to comply with the provisions of the agreement. Specifically, while emissions should have increased by a maximum of 15% compared to 1990 in the years 2008–2012, they increased by 44.7% in 2008, and it was only the economic crisis that allowed this increase to be mitigated a little, with a reduction to 24.0% in 2012. Following on from the difficulty of complying with this agreement, there are now more ambitious objectives at the European level for the coming years. In the second commitment period of the Kyoto agreement (2013–2020), the European Union undertook to reduce emissions by 20% below those of 1990, in addition to making commitments to increase energy efficiency by 20% by reducing energy consumption and to increase the use of renewables to 20% of the energy used. Emissions from sectors included in the EU Emissions Trading Scheme (ETS) (among them the electricity and heat generating sector) should be reduced by 21% in 2020 compared to 2005, while for sectors not included in the ETS, Spain has to reduce its emissions by 10%. By 2030, the objective of the European Union, in order to fulfil its commitments in the Paris Agreement, is to reduce emissions by at least 40% compared to 1990. The sectors included in the ETS must reduce their emissions by 43%, while those not included must do so by 30%, with Spain’s commitment being a 26% reduction.

In this context, there has been an impressive increase, of 81.49%, in the generation of electricity in Spain between 1990 and 2017. However, the emissions of greenhouse gases associated with the generation of electricity have only increased by 4.12% (EC, 2019). In fact, the only reason why they did not decrease in the period was a small rebound in 2017 caused by the greater use of natural gas and coal in thermal power plants in a year of low hydraulic production due to drought. However, the moderate increase in emissions arising from electricity generation has not been enough to contain the total growth of emissions, and much remains to be done to meet the reduction targets set. Various factors have contributed to the evolution of emissions associated with electricity, and there have been different stages in the evolution during that period. Among the aspects that have influenced the trajectory of these emissions are changes in the intensity of electricity use in production, changes in the composition by energy sources, and changes in the efficiency of transformation, among other factors that we will analyse in this paper.

One issue that shows the importance of analysing the emissions from the electricity sector is the progressive electrification of the final energy use. While in 1990 electricity represented 19.7% of the total final energy consumed, in 2017 this percentage had risen to 25.4% (EC, 2019), a process that may be greatly accentuated in future years with the progressive introduction of electric vehicles and technologies such as green hydrogen, power-to-gas and power-to-heat, in the more distant future. On the other hand, emissions from the electricity and heat generation sector represented 27.8% of total CO_2 emissions in 1990 compared to 23.3% in 2017 (22.5% compared to 19.3% if we take the total greenhouse gas emissions) (EC, 2019). The significant volume of these emissions, the long way that there is to go to achieve the established objectives, as well as the potential of the sector for reductions in its transition to a system based entirely on renewable energy sources, give particular interest to an analysis of the factors that affect the emissions from electricity generation. Such an analysis can help us to understand the evolution of these emissions, to evaluate the success of the measures that are implemented, and to guide the measures that are proposed to achieve the stated objectives. A highly useful type of analysis for studying changes in the level of emissions, widely used in energy economics, is index decomposition analysis (IDA). IDA allows us to quantify the impact that different factors have had on the emissions trajectory throughout the period of analysis. This paper develops an application of IDA to determine the main driving forces behind the changes in the emissions associated with the electricity generation sector, and derives a series of public policy implications. Our research will guide decision-making, since it will indicate the aspects of public policy that have the greatest influence on measures that are effective in reducing emissions. This is the first work to apply this decomposition methodology to analyse the determinants of CO_2 emissions for the Spanish electricity sector.

The rest of the article is organised as follows: Section 2 presents the methodological framework and data used in the analysis; Section 3 presents and discusses the results; Section 4 contains the main conclusions and policy implications of the work.

2. Methodological framework and data

Our analytical approach starts from that proposed by Zhang et al. (2013), who developed a factorial decomposition analysis of CO_2 emissions linked to electricity generation in China. Subsequently, the International Energy Agency carried out a similar application in order to discover the drivers of trends in CO_2 emissions associated with electricity generation (IEA, 2015, pp. 32–33; and subsequent editions of the document *CO_2 Emission from Fuel Combustion. Highlights*), although the IEA's calculation does not consider the relationship between emissions and the evolution of GDP.

In the present work, we start from the following identity to express the CO_2 emissions resulting from the use of fossil fuels in the generation of electricity (CO_2E) based on different explanatory factors[1]:

$$\text{(1)} \quad CO_2E \equiv (CO_2E/FEI) \times (FEI/FEG) \times (FEG/TEG) \times (TEG/GDP) \times GDP$$

in which *FEI* reflects the fossil fuel energy input used in the production of electricity; *FEG* denotes the electricity generated from fossil origins; *TEG* is the total electrical energy generated; and *GDP* is the gross domestic product in euros at constant prices and exchange rates.

Expression (1), which is an extended version of the Kaya (1989) identity, decomposes the CO_2 emissions generated in obtaining electricity into five explanatory factors that represent the driving forces of CO_2 emissions in electricity generation. The meaning of each of these factors is as follows:

$c = CO_2E/FEI$ is the *carbonisation factor* of fossil fuel energy used in electricity generation, that is, the emissions per unit of fossil fuel energy used in electricity generation;

$e = FEI/FEG$, the *transformation factor*, is the inverse expression of the efficiency in the conversion of inputs of fossil fuel into electricity;

[1] All greenhouse gas emissions expressed in their CO_2 equivalent have been included in the analysis. However, the magnitude of the other greenhouse gases with respect to the total emissions in obtaining electricity is insignificant (0.4% in 1990 and 0.9% in 2017), so hereafter we will refer to the total amount of emissions in their CO_2 equivalent as CO_2 emissions.

s = FEG/TEG, the *fossil intensity factor*, denotes the share of the electricity of fossil origin in the total electricity generated in the system;

w = TEG/GDP, the *electricity intensity factor*, expresses the electricity intensity of economic activity, an apparent, although very general, efficiency factor in the use of electrical power by economic agents; and

y = GDP, the *production factor*, is the production obtained by the economic system, which constitutes an element of scale. If the rest of the components were to remain constant, the variations in GDP would determine the path that emissions (production) would follow. In Sun (1999) this variation linked to GDP is considered to be the 'theoretical growth' of emissions.[2]

Let $C = CO_2E$. The expression (1), for a given moment of time, could then be written as:

$$(2) \quad C_t \equiv c_t \cdot e_t \cdot s_t \cdot w_t \cdot y_t$$

The difference in emission levels between two years would be:

$$(3) \quad \Delta C = C_t - C_{t-1} = c_t \cdot e_t \cdot s_t \cdot w_t \cdot y_t - c_{t-1} \cdot e_{t-1} \cdot s_{t-1} \cdot w_{t-1} \cdot y_{t-1}$$

From expression (3), the evolution of CO_2 emissions resulting from the generation of electrical power in Spain can be explained by five effects resulting from the evolution of the five defined factors:

$$(4) \quad \Delta C = \Delta C_{c-effect} + \Delta C_{e-effect} + \Delta C_{s-effect} + \Delta C_{w-effect} + \Delta C_{y-effect}$$

There are multiple decomposition methods that can be used for this additive decomposition and to analyse the evolution of the different effects over time. Ang and Zhang (2000) present a review of these methods and their application in environmental

[2] Another scale variable could be chosen; for example Wang et al. (2005), in a study on the historical evolution of CO_2 emissions in China, take the population linked to production per capita as such, linking theoretical growth to the conjunction of these two variables (that is, the GDP effect is decomposed into the effects of population and GDP per capita, identifying these as the factors that would determine the 'theoretical variation' in emissions).

and energy studies. Ang (2004) analyses the different decomposition methods, indicating their respective advantages and disadvantages, concluding that the logarithmic mean Divisia index (LMDI) method is the one that has the best properties. Among its advantages, the fact that the method ensures perfect decomposition, thus avoiding the problem of unallocated residues in the decomposition, stands out. Ang (2004) presents the properties, as well as the theoretical consistency, of the method, in detail. There is consensus in the literature on the suitability of LMDI, so this decomposition method has been used extensively in energy analysis (see e.g., Baležentis et al. 2011; Lin and Long, 2014; Zhao et al., 2014), CO_2 emissions analysis (see, e.g.: Ang and Zhang, 1999; Zhang and Ang, 2001; Wang et al., 2005; Ma and Stern, 2006; Hatzigeorgiou et al., 2009) or, more specifically, the analysis of emissions from electricity generation, such as the aforementioned study by Zhang et al. (2013) for the case of China.

Following Ang (2005), the variation over time of the different effects is given by the following expressions:

$$(5) \quad \Delta C_{c-effect} = L(C_t, C_{t-1}) \ln(c_t / c_{t-1})$$

$$(6) \quad \Delta C_{c-effect} = L(C_t, C_{t-1}) \ln(c_t / c_{t-1})$$

$$(7) \quad \Delta C_{e-effect} = L(C_t, C_{t-1}) \ln(e_t / e_{t-1})$$

$$(8) \quad \Delta C_{s-effect} = L(C_t, C_{t-1}) \ln(s_t / s_{t-1})$$

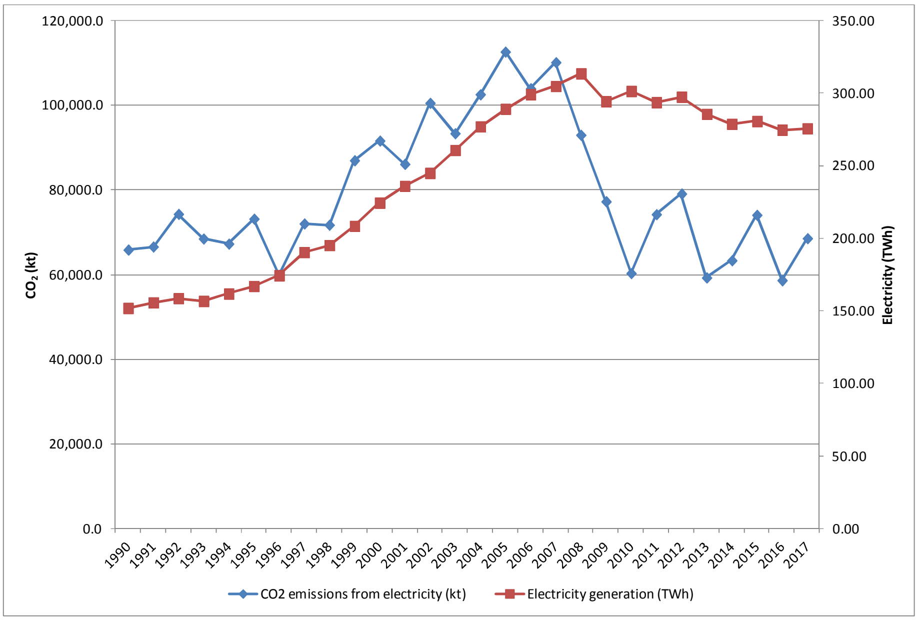
$$(9) \quad \Delta C_{w-effect} = L(C_t, C_{t-1}) \ln(w_t / w_{t-1})$$

$$(10) \quad \Delta C_{y-effect} = L(C_t, C_{t-1}) \ln(y_t / y_{t-1})$$

where $L(C_t, C_{t-1}) = C_t - C_{t-1} \big/ \ln(C_t / C_{t-1})$ for $C_t \neq C_{t-1}$
and $L(C_t, C_{t-1}) = C_{t-1}$ for $C_t = C_{t-1}$

Based on the data provided by the General Directorate for Energy of the European Commission (EC, 2019), we prepared the information contained in Annex 1. All the results of this work are based on the information in that database, which has allowed us to work with perfectly homogenised data, thus avoiding the adjustment problems that arise when using different sources. In Figure 1 we can see the general behaviour of electricity generation and associated emissions during the period under consideration.

Figure 1. Electricity generation and associated emissions

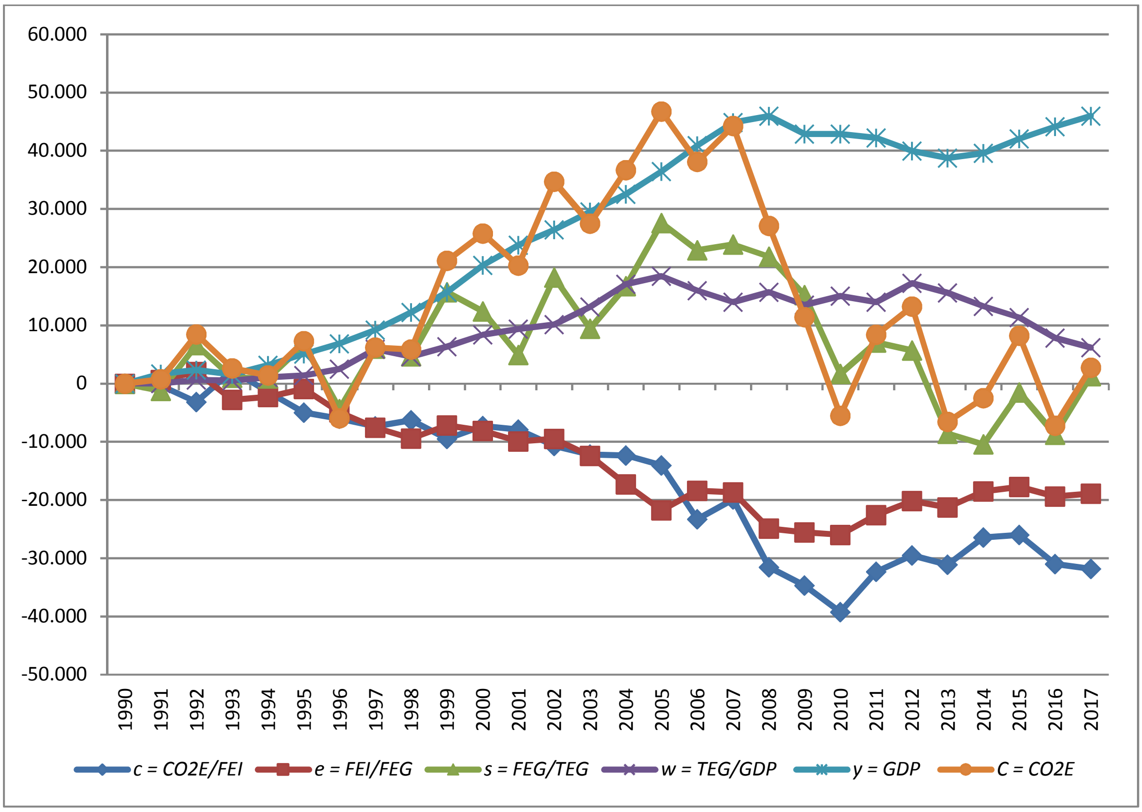


As shown in Figure 1, there was a large increase in electricity generation between 1990 and 2008, although from the beginning of the economic crisis this process slowed down and, even in the years of economic recovery, generation of electricity did not increase, thus leading to a reduction in the intensity of electricity energy in the Spanish economy over these years. In addition, although the CO_2 emissions from electricity show a similarly increasing trend until 2007, from that year on there seems to be a very clear decoupling between the evolution of emissions and that of electricity generation. Four stages can be distinguished in the evolution of emissions, which will be taken into account in the subsequent analysis. First, there is some stability between 1990 and 1998, then strong growth until 2005, followed by a sharp reduction between this year and 2010, and, finally, there is a more erratic evolution, with oscillations, during the last few years of the sample.

3. Results

From the EC (2019) information provided in Annex 1 we computed expressions (5) to (10). The results obtained are presented in Annex 2 and Figure 2. These results quantify the influence of the different explanatory effects on the trajectory of CO_2 emissions from electricity production.

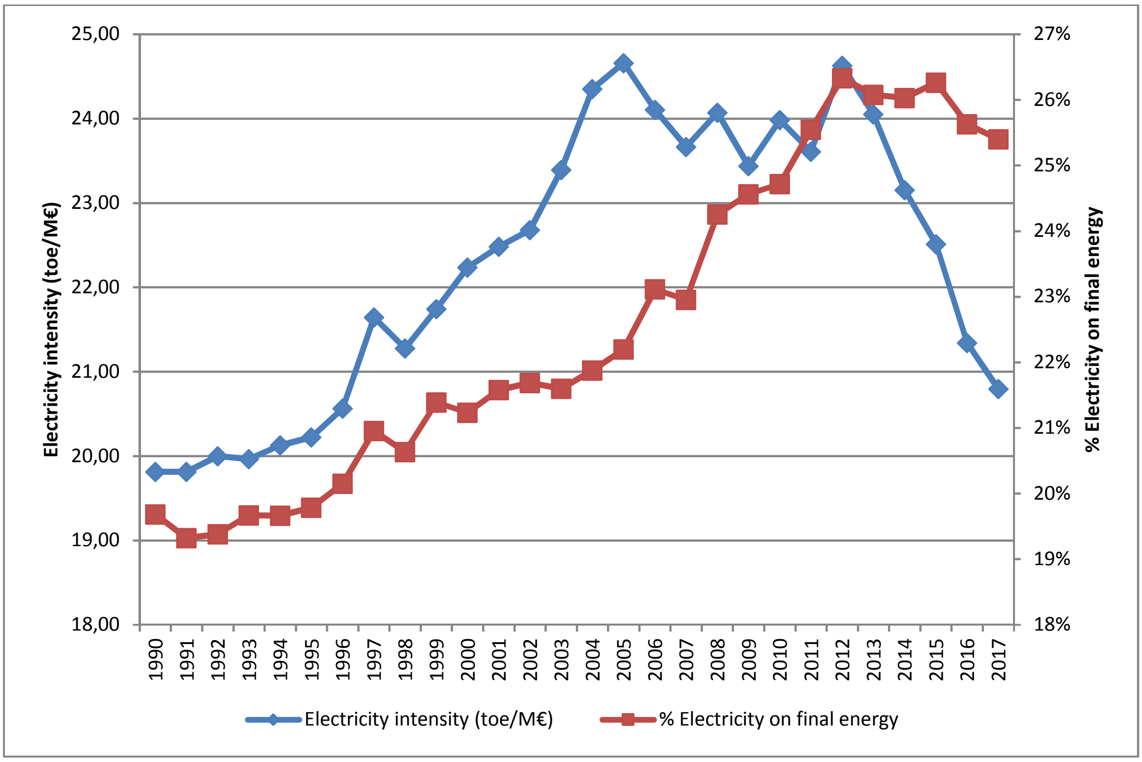
Figure 2. Decomposition of the variation of CO_2 emissions from electricity generation by explanatory effects (kt)



The different effects show very different behaviours over the period. Comparing the trajectory of emissions with the production effect (*y*), we see that they have a similar trend from 1996 to 2007, the year before the crisis, although the behaviour fluctuates much more in the case of emissions from electricity generation, with years when there is economic growth and a significant reduction in emissions caused by the other effects. This would indicate that until 2007 there was an offset among the other effects, so that the emissions were similar to the ‘theoretical’ emissions associated with economic growth. However, from 2008 onwards, including during the years of the economic recovery that has taken place since 2014, the other effects are much more important than GDP in explaining the evolution of emissions.

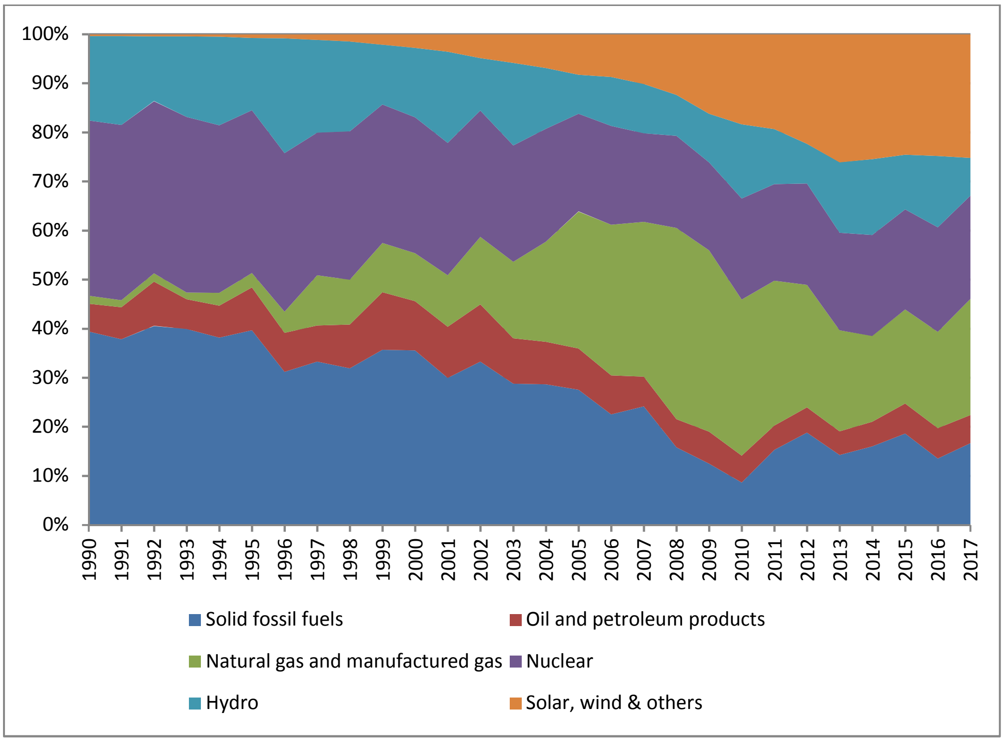
Regarding the electricity intensity of production (w), this effect increases its contribution to the increase in emissions until 2005, but from 2012 onwards there is a significant reduction. The evolution until 2005 is largely caused by the electrification process of the Spanish economy, discussed in the introduction, and this continues until 2012, stabilising downwards in later years (see Figure 3). However, despite the stabilisation in the degree of electrification, between 2012 and 2017 there is a sharp reduction in electricity intensity, leading to a much lower impact of this effect on emissions at the end of the period. This could be due either to a gradual improvement in the efficiency in the use of electricity or to a reduction in the specialisation in intensive productions in the use of electricity, given that the percentage that electricity represents of the total final energy is not substantially modified.

Figure 3. GDP electric intensity (toe/M €) and degree of electrification of energy



Going back to Figure 2, the carbonisation effect of fossil fuel energy (*c*) shows a clear downward trend between 1993 and 2010, except in some years. This reduction is the result of the reduction of coal and the increase of natural gas in the electricity mix (Figure 3). However, this effect rebounds after 2010, as a result of a certain recovery in the use of coal. Regarding the efficiency in the transformation of fossil fuels into electricity (*e*), this has a behaviour parallel to the carbonisation effect. This could be explained by the same fact, given the greater efficiency in the conversion of natural gas to electricity and new combined cycle power plants, compared to conventional coal-fired power plants. Regarding the effect of the proportion of fossil sources with respect to the total (*s*), we see an evolution similar to that of total emissions, although more attenuated, with a clear growth from 1996, a maximum contribution to emissions in 2005 (the year of maximum emissions), and a subsequent reduction to a point where there is almost no impact on total emissions at the end of the period. To understand the evolution of these last three effects, Figure 4 is particularly useful, as it shows the mix of energy sources used for electricity generation in the period analysed.

Figure 4. Energy mix of electricity generation (%)



The strong increase, in both absolute and relative terms, in the contribution of renewables to electricity generation stands out. This increase was accompanied by a much larger increase in natural gas until 2008, which explains why, despite the increase in renewables, the contribution of the fossil fuel energy ratio effect does not decrease until the combined reduction of coal, which falls from 2005, and natural gas, which falls from 2008, occurs. While the contribution of hydroelectric generation oscillates, depending on weather variables, the other renewables had a growing trend until 2012, when there was an important change in the legislation that regulates the implementation of renewable energy (Royal Decree-Law 1/2012). This legislation cancelled the economic incentives for the installation of new electricity generation plants using renewables, co-generation and waste, in addition to other complementary measures cutting incentives in order to reduce the so-called 'electricity tariff deficit'.[3]

In order to focus on structural changes throughout the period analysed rather than on changes with a more cyclical nature, we prepared Table 1, taking into account the relevant

[3] This term would cover the shortfall of revenues that arises when the regulated components of retail electricity tariffs are allegedly below the corresponding costs borne by power companies.

periods arising from the trajectory of CO_2 emissions from electricity that we see in Figure 1.

Table 1. Average evolution of the explanatory effects and periods considered (kt, %)

	c = CO2E/FEI	*e = FEI/FEG*	*s = FEG/TEG*	*w = TEG/GDP*	*y = GDP*	*C = CO2E*
1991–1998	(-) -789.1	(--) -1,176.2	(+) 586.4	(+) 582.2	(++) 1,531.0	(+) 734.3
%	-107.5	-160.2	79.9	79.3	208.5	100.0
1999–2005	(-) -1,103.9	(--) -1,760.7	(+++) 3,273.7	(++) 1,971.0	(+++) 3,460.5	(+++) 5,840.7
%	-18.9	-30.1	56.1	33.7	59.2	100.0
2006–2010	(---) -5,040.4	(-) -847.4	(---) -5,180.4	(-) -679.2	(+) 1,286.2	(----) -10,461.1
%	-48.2	-8.1	-49.5	-6.5	12.3	-100.0
2011–2017	(+) 1,056.6	(+) 1,010.5	(0/-) -61.0	(-) -1,267.6	(+) 441.3	(+) 1,179.9
%	89.6	85.6	-5.2	-107.4	37.4	100.0
	c = CO2E/FEI	*e = FEI/FEG*	*s = FEG/TEG*	*w = TEG/GDP*	*y = GDP*	*C = CO2E*
1991–1998	(-)	(--)	(+)	(+)	(++)	(+)
1999–2005	(-)	(--)	(+++)	(++)	(+++)	(+++)
2006–2010	(---)	(-)	(---)	(-)	(+)	(----)
2011–2017	(+)	(+)	(0/-)	(-)	(+)	(+)
1991–2017	-31,845.2	-18,897.8	1,277.8	6,185.1	45,992.6	2,712.4

Source: prepared by the authors with EC (2019) data.

Note: the (+++) sign indicates a strong contribution of the factor to an increase in emissions; the (---) sign indicates a strong contribution of the factor to a reduction in emissions.

In the first period considered, there was a moderate increase in emissions (734.3t). The main contributor to this increase was the scale effect of the economy (*y*). The impact of the electricity intensity of the economy (*w*) was less, although significant, due to the aforementioned electrification process, and this was the same for the share of fossil fuel energy in total electricity generated (*s*), explained by the increase in the use of natural gas and also of oil in this subperiod (see Figure 4). The emissions reduction associated with the favourable behaviour of the carbonisation effect (*c*) was due to the greater weight of hydraulic power in the period. Regarding the energy transformation effect (*e*), this had a favourable impact on the reduction, also partly due to the greater weight of hydroelectric energy, given that hydroelectric energy is considered, by convention, to have 100% efficiency in its transformation.

The second period, which is shorter than the first, is characterised by the largest increase in emissions (5,840.7t). The main effect affecting this increase was the scale of production (*y*), although the proportion of fossil fuel energy (*s*) had almost the same level of impact. This increase in the period was explained by the increase in the use of natural gas and also of coal. However, the increase in the use of gas was much greater, which explains why the carbonisation of fossil fuel energy effect (*c*) and, above all, the efficiency of transformation effect (*e*) attenuated the strong increase in emissions from the other effects.

The third period (2006–2010), the shortest of all, shows a concentration of the largest emission reduction (-10,461t). The contribution of the production effect (*y*) was smaller than in the other periods, which is explained by the fact that the last three years of this period coincide with the economic crisis. However, this period stands out because the other four effects went in the same direction, contributing to the reduction in emissions. There was a change in the previous trend, with an increase in the electricity intensity of GDP (*w*), and its effect on emissions also changed, while the transformation of fossil fuel into electricity improved, contributing to the lower emissions from this effect (*e*). However, the most important effects in this period, which explain the great reduction in emissions, were those associated with the proportion of electricity power of fossil origin (*s*), which contributed to reducing emissions by 5,180.5t, and the reduction in the carbonisation index (*c*), which reduced them by another 5,040.4t. These issues are associated with the reduction in the use of coal to generate electricity, which during this period was accompanied by a reduction in the contribution from gas, together with the new uses of renewable energy sources, which accelerated their expansion during this period.

In the last period (2011–2017), the progress in reducing emissions that was made during the previous period was reversed. Although the contribution of production (*y*) was small and the electricity intensity effect (*w*) helped to contain emissions, an increase in emissions occurred as a result of the carbonisation (*c*) and transformation (*e*) effects. The policies that held back the deployment of renewable energy sources, as well as the recovery in the use of coal in electricity generation, explains the behaviour of these effects and their impact on the growth of emissions.

4. Conclusions and policy implications

The aim of this paper was to develop an IDA application to analyse the main drivers of CO_2 emissions in the electricity generation sector in Spain over the period 1991–2017. The results show different contributions of the different effects to the emissions over time, and also different contributions in specific subperiods.

Several policy implications can be derived from the analysis. First, a larger penetration of renewable energy sources (RES) is a sine qua non for a transition to clean energy. The erratic evolution of RES during the period, and especially in the last decade, shows that the evolution of CO_2 emissions is highly correlated with the penetration levels of RES. When this penetration increased strongly (as it did between 2005 and 2011), the share of fossil fuels in the electricity mix went down and emissions were reduced. In contrast, the cost-containment measures in the RES sector in 2010 and 2011, and especially the moratorium in 2012, led to a collapse of the sector, and to significant increases in emissions. These measures were taken in a particular setting. The Spanish context at the time was a high tariff deficit (to which RES contributed), a meagre electricity demand as a result of the economic and financial crisis, and overcapacity, but the measures were difficult to justify in terms of the objective to achieve a clean energy transition.

However, the outlook seems to be more promising in this regard. Three renewable energy auctions were organised under the new regulatory package 2013/2014. Although quite a high volume was auctioned (8.7 GW), our data do not show their impact, since contracts were awarded in 2016 and 2017, and most projects were only built in 2019. Even more important is the future evolution envisaged in the new National Integrated Plan on Energy and Climate (PNIEC). Under this plan, 50 GW of RES will need to be deployed until 2030 in order to comply with the goal of a 74% penetration of RES in the electricity sector. Different types of measures will be adopted (see MITECO, 2020). Our results suggest that this is completely justifiable if the aim is to have an intense decarbonisation of the electricity sector. Political commitment to increase RES penetration is therefore the main requirement for a clean energy transition.

Complementary to this substantial increase in renewable energy sources are measures to reduce the share of fossil fuels in the electricity mix. Fortunately, the costs of renewable energy sources have gone down substantially and some (solar photovoltaic and onshore wind) are already cost-competitive with respect to their fossil-fuel counterparts. Therefore, measures will only need to accelerate a natural economic process towards the phasing out of fossil fuels, taking into account the ambitious RES targets in terms of RES penetration mentioned above.

Our results suggest that the dash for gas in the early years of the analysed period led to a reduction in the fossil fuel carbon factor. Gas, which is a cleaner fossil fuel than coal or fuel-oil, will still be needed in the coming years of the energy transition as a source of electricity generation, as a back-up to the variable RES generation, particularly at peak-load times. The currently low gas prices and relatively high coal prices suggest that, within the fossil fuel mix, market trends will naturally lead to the adoption of the cleaner alternative (gas) to the detriment of the more carbon-intensive one (coal). The increasing and relatively high carbon price of around 20€/tCO_2 in the ETS will only reinforce this trend. Our results suggest that this penetration of gas can contribute to decarbonisation in the initial years of the energy transition, when gas replaces other, more polluting, fossil fuel sources, but that it is not a main driver of an ambitious transition to clean energy. Indeed, while its role in electricity generation will be relevant in the coming years, as a back-up to RES, it can be expected to lose importance over the period. This also has an important implication in terms of the role that can be played by the ETS as a complementary instrument to accelerate the transition.

The improvements in fossil fuel technical efficiencies (conversion factors) over the analysed period, which have led to a lower primary/final energy ratio and contributed to a reduction in CO_2 emissions, indicate that technological changes in fossil fuel technologies have played some role in the decarbonisation, but this role has, however, been quite limited. Most importantly, it is likely that these improvements have reached a plateau, which is the case for highly mature technologies for which only very incremental improvements can be expected. Therefore, they will not be an important factor for the decarbonisation of the electricity sector in the future, and specific policy interventions in this context, beyond a strong EU ETS with an appropriate carbon signal, cannot be recommended.

Finally, further research is needed to interpret the contribution of the electricity intensity of GDP (measured as electricity consumption per unit of GDP) to the emissions reductions in Spain, and the future outlook for this. Our results indicate a trend of a contribution to the increase in CO_2 emissions over the analysed period. However, two opposing trends can be discerned in this context, each with different energy transition and public policy implications for the future. On the one hand, a higher electricity consumption/GDP ratio may suggest a lower electricity efficiency in the economy. If so, this greater inefficiency in electricity consumption would contribute negatively to a decarbonised energy transition. However, on the other hand, a higher ratio can also mean a higher electrification rate of the economy, which is widely considered to be a main component of the energy transition (see, e.g., IRENA, 2020) because the coupling between electrification and sectors is regarded as a cost-efficient way to decarbonise non-electricity sectors, particularly transport. Two main policy implications derive from this analysis. First, measures could be adopted to increase the electricity efficiency of production processes, maybe through subsidies on the purchase of electricity-efficient equipment. Second, and most importantly, measures should be adopted to accelerate the electrification rate of the transport sector through, for example, subsidies on the purchase of electric cars and support for the implementation of an appropriate network of charging points.

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Annex 1. Data of the variables used for computing the main drivers on CO_2 emissions from electricity generation

	Input transformation		Electricity generation			
	Fossil fuels Ktoe	Non fossil fuels Ktoe	From fossil fuels Ktoe	Total Ktoe	GDP (Billion EUR 2010)	GHG from Electricity kt CO2-eq.
1990	16,719.2	16,375.0	6,096.8	13,063.0	659.3	65,864.3
1991	16,987.1	16,893.6	6,136.0	13,396.5	676.0	66,586.7
1992	19,739.4	16,362.5	6,991.9	13,647.6	682.3	74,296.6
1993	16,851.0	16,838.7	6,384.8	13,482.5	675.3	68,477.0
1994	17,499.5	16,953.5	6,580.3	13,916.9	691.4	67,283.6
1995	20,005.9	16,733.3	7,374.5	14,367.2	710.5	73,177.9
1996	16,630.8	18,369.7	6,516.8	15,000.8	729.5	59,902.0
1997	20,424.2	17,769.4	8,330.0	16,371.6	756.4	72,048.2
1998	20,039.4	18,791.2	8,384.5	16,785.6	788.9	71,738.4
1999	25,296.6	18,077.1	10,290.4	17,924.2	824.3	86,971.1
2000	25,992.8	19,810.0	10,681.1	19,300.8	867.9	91,625.8
2001	24,598.8	21,454.8	10,323.0	20,295.4	902.6	86,126.8
2002	29,588.2	20,150.0	12,357.6	21,062.0	928.6	100,527.5
2003	27,905.4	21,898.8	12,008.2	22,416.7	958.2	93,353.3
2004	30,711.1	21,926.1	13,897.2	24,073.4	988.6	102,549.0
2005	34,258.1	19,993.3	16,151.2	25,286.6	1,025.4	112,623.2
2006	34,448.9	21,120.9	15,750.6	25,748.9	1,068.2	103,953.0
2007	35,337.7	20,316.7	16,193.4	26,230.4	1,108.5	110,116.7
2008	33,485.2	21,592.7	16,314.8	26,978.3	1,120.8	92,987.6
2009	28,869.1	21,254.6	14,176.9	25,332.8	1,080.8	77,275.1
2010	24,091.3	25,840.7	11,906.1	25,926.7	1,080.9	60,317.6
2011	26,751.9	23,954.2	12,571.5	25,266.3	1,070.1	74,242.4
2012	27,466.9	25,890.4	12,503.9	25,585.4	1,038.8	79,107.7
2013	21,069.4	27,494.7	9,743.1	24,559.9	1,021.1	59,291.8
2014	20,869.6	27,628.9	9,232.6	23,968.1	1,035.2	63,360.9
2015	24,241.7	26,513.8	10,600.0	24,154.0	1,072.9	74,081.9
2016	20,697.0	27,519.4	9,283.9	23,626.3	1,106.9	58,644.7
2017	24,534.1	26,064.8	10,917.1	23,708.2	1,139.9	68,576.7

Note: fossil fuels include solid fossil fuels (coal), oil and petroleum products, manufactured gases, natural gas, and non-renewable waste.

Source: Prepared by the authors with EC (2019) data.

Annex 2. Decomposition of the variation of emissions in explanatory effects

	c = CO2E/FEI	*e = FEI/FEG*	*s = FEG/TEG*	*w = TEG/GDP*	*y = GDP*	*C = CO2E*
1990	0	0	0	0	0	0
1991	-330.3	628.1	-1,244.7	5.9	1,663.3	722.4
1992	-2,857.5	1,378.5	7,881.8	655.5	651.6	7,709.9
1993	5,468.0	-4,806.6	-5,612.7	-128.7	-739.6	-5,819.6
1994	-3,756.6	515.7	-104.5	553.5	1,598.6	-1,193.4
1995	-3,500.8	1,397.6	5,762.4	325.9	1,909.2	5,894.4
1996	-1,022.2	-4,053.8	-11,062.1	1,111.6	1,750.6	-13,275.9
1997	-1,370.9	-2,633.0	10,397.1	3,369.4	2,383.6	12,146.2
1998	1,057.6	-1,836.3	-1,326.1	-1,235.8	3,030.9	-309.8
1999	-3,197.6	2,226.8	11,011.0	1,721.8	3,470.7	15,232.6
2000	2,230.7	-903.0	-3,278.7	2,004.4	4,601.4	4,654.7
2001	-601.2	-1,868.4	-7,494.0	979.1	3,485.6	-5,499.0
2002	-2,800.6	445.7	13,302.4	808.7	2,644.5	14,400.7
2003	-1,500.3	-2,894.4	-8,819.5	2,999.6	3,040.4	-7,174.2
2004	-181.7	-4,922.4	7,320.8	3,927.5	3,051.5	9,195.7
2005	-1,676.3	-4,409.4	10,874.0	1,356.0	3,929.8	10,074.1
2006	-9,271.4	3,320.0	-4,679.8	-2,464.9	4,425.9	-8,670.2
2007	3,438.0	-241.1	984.4	-1,976.5	3,958.9	6,163.7
2008	-11,673.6	-6,211.9	-2,091.8	1,722.3	1,126.1	-17,129.0
2009	-3,120.8	-668.7	-6,580.4	-2,253.3	-3,089.3	-15,712.5
2010	-4,574.1	-435.0	-13,534.6	1,576.6	9.6	-16,957.5
2011	6,902.0	3,377.2	5,375.1	-1,056.7	-672.9	13,924.7
2012	2,843.6	2,434.7	-1,375.0	3,239.6	-2,277.6	4,865.4
2013	-1,593.0	-1,077.7	-14,333.8	-1,629.0	-1,182.3	-19,815.9
2014	4,653.4	2,715.3	-1,804.3	-2,335.4	840.2	4,069.1
2015	448.8	800.1	8,942.1	-1,925.2	2,455.1	10,721.0
2016	-4,993.5	-1,685.6	-7,298.5	-3,522.9	2,063.3	-15,437.2
2017	-864.8	509.8	10,067.2	-1,643.9	1,863.6	9,932.0

Source: Prepared by the authors with EC (2019) data.

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