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Current expectations and actual values for the clean spark spread: The case of Spain in the Covid-19 crisis

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ABSTRACT

The Covid-19 crisis has had a major impact on electricity markets, affecting power plant input and output prices. In this paper Spanish electricity and natural gas prices and international carbon prices are used to calculate the variable margin of natural gas combined cycles (NGCC), i.e. the Clean Spark Spread (CSS). The stochastic behavior of the CSS is modeled using an Ornstein-Uhlenbeck (OU) process because of its properties. The expected first semester 2020 CSS results based on the fitted model with daily 2016-2019 data, taking the end of 2019 as a starting point, are compared with the actual figures for the same period. In the first half of 2020 electricity and natural gas prices are significantly lower than expected at the end of 2019, but carbon allowance prices have decreased less in percentage terms. The monthly CSS values in the first half of 2020 are significantly lower than expected for March-May 2020, with the April value being -€4.15/WWh lower figure than the €7.16/MWh expected. This work calculates distributions of daily and monthly CSS values.

1. Introduction

The Covid-19 crisis has significantly affected wholesale energy markets, reducing energy demand and prices. Its effects have been felt in all sectors in the first months of 2020, including Construction and Industry (REE, 2020a), though its effects have differed from sector to sector. The year-on-year variation in Spanish GDP stands at −21.5%, compared to −4.2% in the preceding quarter. This figure breaks down as −23.8% for Industry, −27.5 for Construction and −21.3% for Services (INE, 2020).

According to IEA (2020a) Covid-19 has caused a decrease in investments and threatens to slow the expansion of key clean energy technologies.

In the first months of 2020 Covid-19 and mild winter temperatures in the northern hemisphere have resulted in global natural gas markets experiencing the largest recorded negative demand shock in their history (IEA, 2020b).

On December 31, 2019 China reported a cluster of cases of pneumonia, and a novel coronavirus was eventually identified as the culprit (WHO, 2020). This disclosure has led to the end of 2019 being taken as the date when international markets began to become aware of the pandemic. Four years (2016–2019) of daily data on Spanish electricity, natural gas and international carbon prices are used to model and calculate parameters before the Covid-19 pandemic and the resulting figures are used to simulate what the results would have been without the pandemic.

In Spain, March 13, 2020 saw the introduction of a state of emergency. Lockdown conditions were further tightened on March 30, 2020, with non-essential activities being banned. Construction and some industries returned to work on April 13, 2020, so the most severe measures were in place for 14 days.

The Covid-19 pandemic has affected Spanish wholesale markets and therefore the profitability of electric power plants.

The Clean Spark Spread (CSS) is the variable margin of a natural gas combined cycle (NGCC) power plant, being the price of electricity minus the cost of natural gas and the emission allowances necessary to produce it. It is therefore a margin that takes into account a penalty for the CO_2 emitted. This margin is the fundamental factor that determines whether or not an NGCC power plant generates electricity at any given time. In Spain and many other Western countries coal and nuclear plants are closing and the installed power from renewables is increasing. With this trend, NGCC power plants can play an important role in guaranteeing security of supply at hours of maximum annual demand. That effect may increase over time due to greater electrification of the economy, e.g. the development of electric vehicles (Abadie and Chamorro, 2020).

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This paper sets out to analyse forecasts based on 2016–2019 data, using the end of 2019 as its starting point and actual figures for the first half of 2020 to gauge the extent to which the Covid-19 crisis and the mild winter temperatures have affected the CSS. Probability distributions for estimations have been constructed based on an Ornstein-Uhlenbeck (OU) process calibrated with daily electricity, natural gas and carbon quotes for 2016–2019 and using the closing data for 2019 as the starting point for simulating future values. The expected values are compared with the current values for the first half of 2020.

Fig. 1 uses REE data to show the trend in monthly NGCC generation, which shows decrease in the first months of 2020. In those months the % of NGCC generation was lower than usual, with a figure of 6.93% being recorded in March 2020.

The Covid-19 crisis has affected the Levelised Cost of Electricity (LCOE), calculated as described by Abadie and Chamorro (2019). In some cases cost has been reduced, e.g. for natural gas combined cycles. But in all cases the income of generation plants has been greatly reduced due to the drop in electricity prices. Net income has been affected at renewable energy plants, where costs have not decreased.

Some of the papers that have analysed the Clean Spark Spread (CSS) are the following.

Elias et al. (2016) analyse a spark spread and clean spark spread option-based valuation of a power plant with multiple gas turbines using lattices.

Martinez and Torró (2018) discusses spark spread risk management using electricity and natural gas futures.

The relationship between electricity and natural gas prices in Spanish wholesale markets is analysed by Furió and Población (2018), and it is concluded that natural gas and electricity prices are not only cointegrated but also share common long-term dynamics.

Carmona et al. (2012) present a pricing method for clean spread options with a set of numerical examples.

Elias et al. (2018) use a real-options approach to assess the value of retrofitting carbon capture and storage technology to an existing natural gas-fired base-load power plant. Clean Spark Spread options are used to calculate the plant value. Two alternative storage technologies are assessed using mean reverting processes for electricity and natural gas prices.

Nowotarski and Weron (2018) review Electricity Price Forecasting methods.

Esquivel-Patiño and Rivera (2019) conduct an environmental and energy analysis of a natural gas combined cycle (NGCC) power plant integrated with post-combustion carbon capture and an organic Rankine cycle.

Natural Gas Combined Cycle (NGCC) power plants are considered as flexible, low-carbon sources of electricity (Bannör et al., 2016) that can facilitate the transition to low-carbon electricity generation. They can help to maintain a level of security of electricity supply in a generation mix with a high proportion of renewables at times of maximum demand (Abadie and Chamorro, 2020). Economic literature shows than the CSS is a relevant value when analysing the profitability and risk of NGCC power plants, as per Hentschel et al. (2016) and Bannör et al. (2016).

There is an incipient and growing literature that analyzes the effects of the covid-19 pandemic, some of these works are cited below.

The impacts of Covid-19 pandemic in air transport mobility during the four months for 2020 was analysed by Nižetić (2020) using two airports in Croatia. The author's results the reduction of more than 96% in s air transport mobility for selected airports.

The effects of Covid-19 pandemic in hourly demand in Ontario was analysed by Abu-Rayash and Dincer (2020) showing that the overall electricity demand of this province for the month of April of this year amidst pandemic conditions declined by 14%. Their conclusions show that hourly electricity demand shows a clear curve flattening during the pandemic accompanied by a reduction in CO2

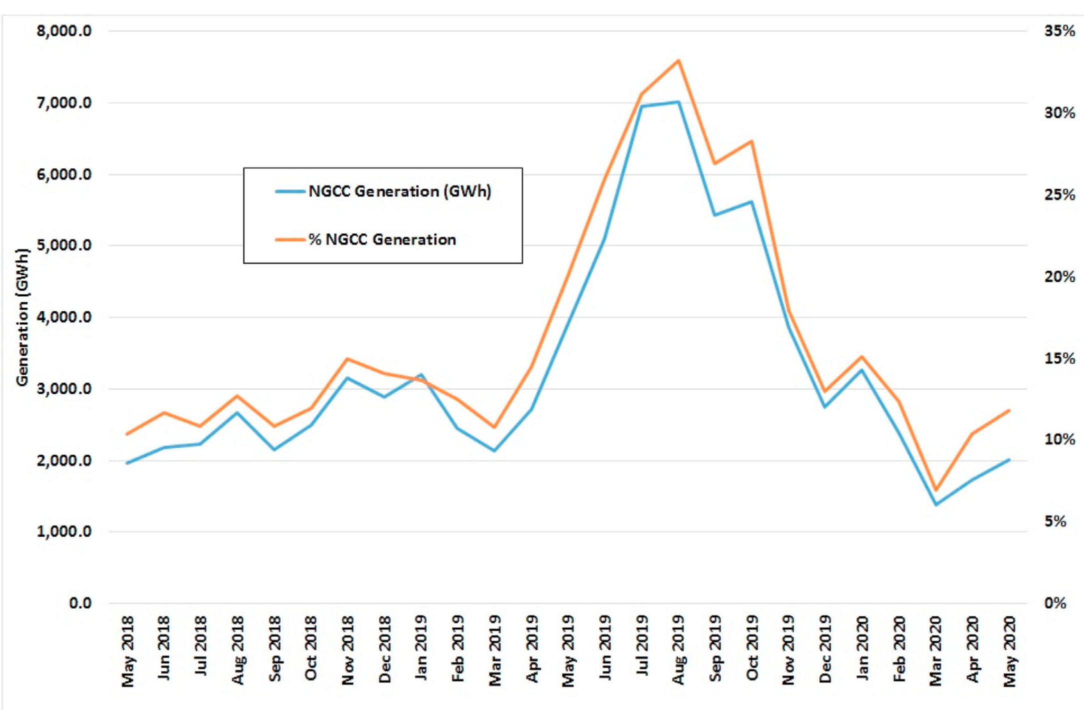

Fig. 1. Spanish monthly NGCC electricity generation in GWh and as a percentage of the total.
Source: own work based on data from REE monthly bulletins (REE, 2020b).

emissions. This paper expands on the aspects of a smart city by including energy, resources and pandemic resiliency. The work uses indicators to categorize into five levels of increasing smartness.

There is an incipient but growing literature that analyses the effects of the Covid-19 pandemic, some examples of which are cited below.

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The new, contemporary challenges of adopting and implementing environmental sustainability policies in the global airline industry at the beginning of the Covid-19 pandemic is studied by Amankwah-Amoah (2020).

The status of renewable energy in Malaysia and the initiatives taken to promote solar photovoltaic (PV) technology to meet energy demands via a low-carbon pathway is studied by Vaka et al. (2020). The authors state that beyond Covid-19, a collective effort is needed on the part of the Government, industries and small players to accomplish this vision.

The effects of private restriction policies on air pollution in China before and after the outbreak of Covid-19 are analysed by Chen et al. (2021).

The research presented here proposes a different methodology for analysing the impacts of the pandemic, based on the calibration of a stochastic diffusion model for the CSS with historic daily data. This approach enables expected future values to be obtained without the effects of the pandemic and compared with the actual figures for the first half of 2020. The daily expected values can be summarised to provide monthly expected figures and compared with official statistical information. The methodology proposed also enables the distribution of future values to be obtained for before the beginning of the Covid-19 pandemic, analysing whether or not the actual values can be classed as low-probability extreme events considered as possible before the onset of the pandemic.

The main objective of this paper is to calculate a distribution of monthly CSS values for the six first months of 2020 based on information from before the start of the Covid-19 pandemic, using the proposed stochastic diffusion model, and to compare the actual CSS values with the expected values and percentiles.

2. Material and methods

The variable margin of natural gas combined cycles (NGCC) comprises the Clean Spark Spread (CSS), which is income from electricity minus the natural gas and carbon prices needed to produce one MWh of electricity (Abadie Chamorro, 2009). This value also depends on NGCC plant efficiency and the emission factor of the fuel used. Equation (1) shows the CSS_t margin per MWh at time t of a natural gas-fired power plant that operates under a cap-and-trade system. The carbon price is subtracted from the CSS Equation because $A_t I_G$ is the price of the carbon allowances that a NGCC power plant needs to produce one MWh of electricity.

$$CSS_t = E_t - \frac{G_t}{EF_G} - A_t I_G \tag{1}$$

Where E_t is the electricity price at time t, G_t is the natural gas price and A_t is the carbon allowance price. EF_G is the natural gas power plant efficiency and $I_G$stands for the power plant emission intensity. According to IPCC (2006), a plant burning natural gas has an emissions factor of 56.1 $kgCO_2/GJ$. Under 100% efficiency conditions consumption would be 3.6 GJ per megawatt-hour, so Equation (2) shows the emission intensity of a power plant depending on its efficiency.

$$I_G = \frac{0.20196}{EF_G}\frac{tCO_2}{MWh} \tag{2}$$

Thus, the complete formula for the CSS margin at time t is as shown in Equation (3):

$$CSS_t = E_t - \frac{1}{EF_G}(G_t + 0.20196A_t) \tag{3}$$

Power plants of this type are highly efficient, thanks to this combined process (the thermal efficiency of a power plant is the saleable energy produced as a percentage of the heating value of the fuel consumed). Their thermal efficiency is between 50% and 60%, with an average of 52.5% (Energy and Society, 2017). Thus, an efficiency rate of $EF_G = 0.525$ in gas plants is selected. The proposed methodology can be used with other efficiency values.

The calculation of CSS parameters and the distribution of their simulated values, including the expected value, comprise an important element in assessing NGCC power plants and also in risk management and hedging at such plants. A higher efficiency ratio enables an NGCC power plant to produce electricity at a profit on more occasions, regardless of initial investment costs.

The CSS historic daily prices for January 2016 to June 2020 are calculated using daily Spanish electricity spot prices for 1461 days from ESIOS (2020), natural gas day ahead prices from the Iberian Gas Market (MIBGAS, 2020) and CO_2 prices from Sendeco2 (2020). The CSS figures are positive in 1233 cases and negative in 228.

Fig. 2 shows the CSS prices calculated using the three sources of data.

Table 1 shows some daily statistics for CSS and also for electricity, natural gas and carbon prices. The mean daily CSS price over the four years is €7.12/MWh. In Table 1 the CSS values show a negative skew, which occurs when the left of the distribution tail is longer and most of the distribution is concentrated on the right side. The CSS distribution has a positive excess kurtosis, the distribution is leptokurtic and it has fatter tails than the normal distribution. It thus deviates somewhat from a normal distribution. Fig. 3 shows the CSS histogram for a fitted normal distribution, where the negative skewness and the leptokurtic shape are shown. The frontier between negative and positive values is at the 18.49% percentile.

Fig. 4 shows the CSS QQ-plot comparing the CSS and normal distributions, showing the quantiles from one to the other. For a near-normal distribution the blue curve should be close to the diagonal line.

3. Theory: the stochastic model of electricity prices and their calibration

There are three stochastic components of CSS with relevant characteristics. Electricity prices have seasonality, holiday effects, trends, mean reversion, volatility and price spikes. Similar

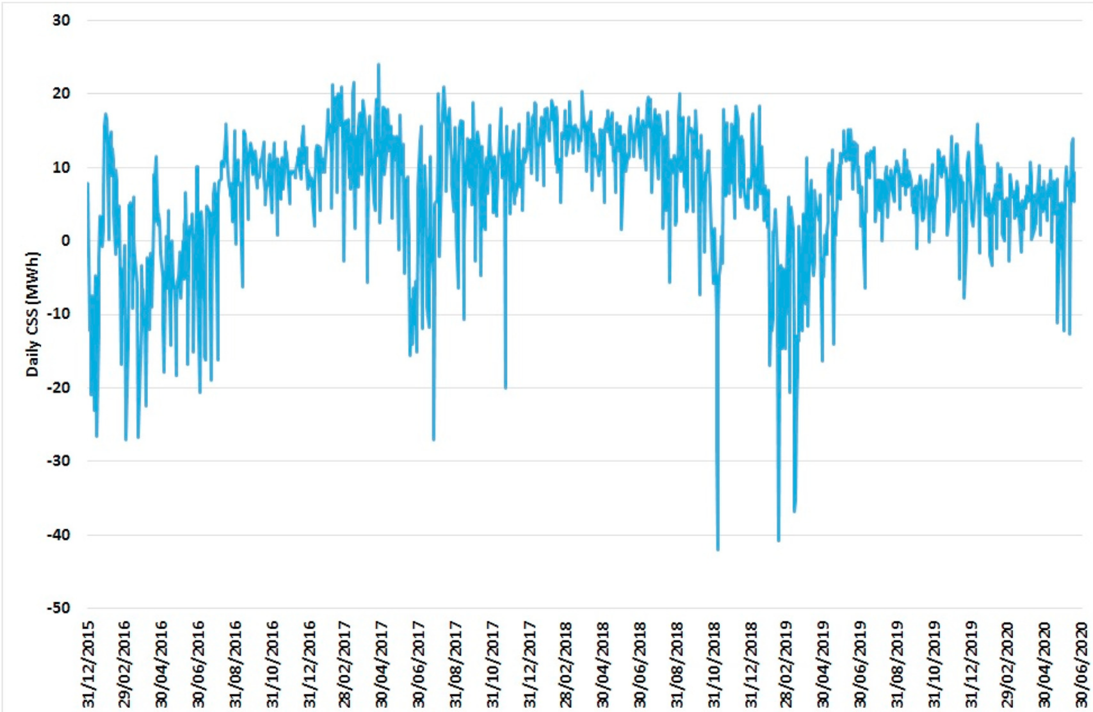

Fig. 2. Spanish daily CSS, January 2016 to June 2020.
Source: Own work based on data from REE, Iberian Gas Market (MIBGAS) and Sendeco2.

Table 1
Daily statistics (2016–2019).

Prices (€/MWh)	Mean	Minimum	Maximum	Standard Deviation	Standard Error	Skewness	Excess Kurtosis	Percentile 5%	Percentile 95%
Electricity Spain (€/MWh)	49.21	1.94	91.88	12.86	0.336	−0.52	0.87	25.41	68.01
Natural Gas Spain (€/MWh)	19.48	7.89	43.00	5.52	0.144	0.85	1.20	10.45	28.16
Carbon(€/tonne)	12.99	3.96	29.77	8.46	0.221	0.49	−1.43	4.57	26.45
CSS (€/MWh)	7.12	−42.04	24.01	8.52	0.223	−1.55	3.72	−10.15	17.39

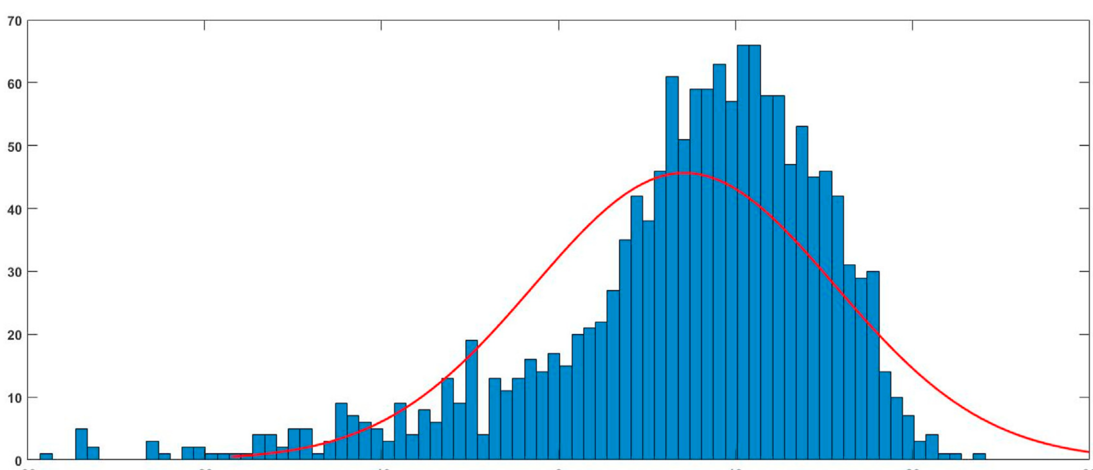

Fig. 3. CSS histogram values and normal fitted distribution.

characteristics are present in the price of natural gas but at very different levels. However, carbon prices are usually assumed to behave as a Geometric Brownian Motion (GBM) process (Abadie and Chamorro, 2013). In this Section the CSS stochastic model is calibrated under the real-world probability measure P.

Fig. 5 shows the daily Spanish electricity and natural gas prices for 2016–2019. It is clear that there is a positive correlation between Spanish electricity and natural gas prices. These markets are connected through the operation of natural gas combined cycle (NGCC) power plants because the CSS is the variable margin.

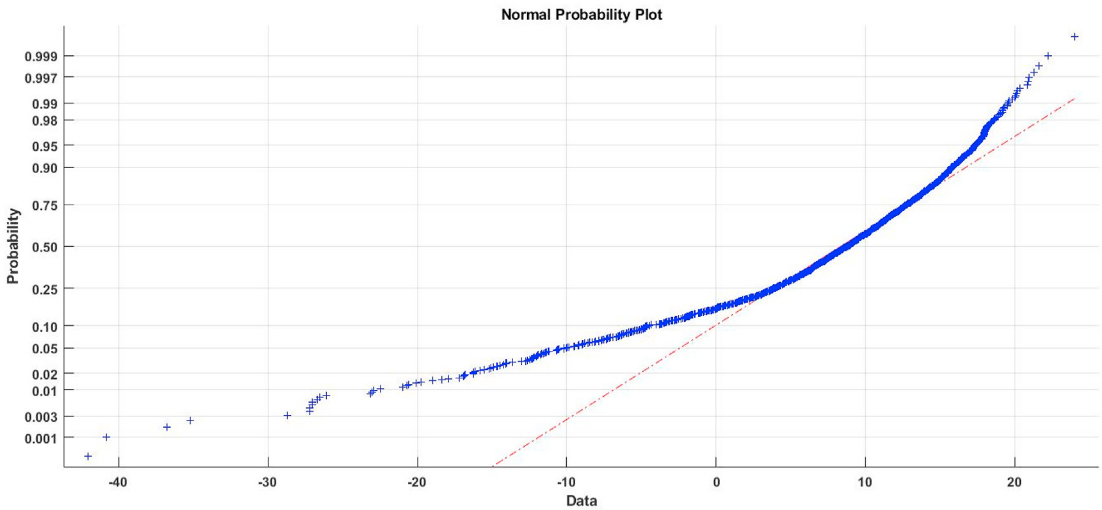

Fig. 4. CSS QQ-plot.

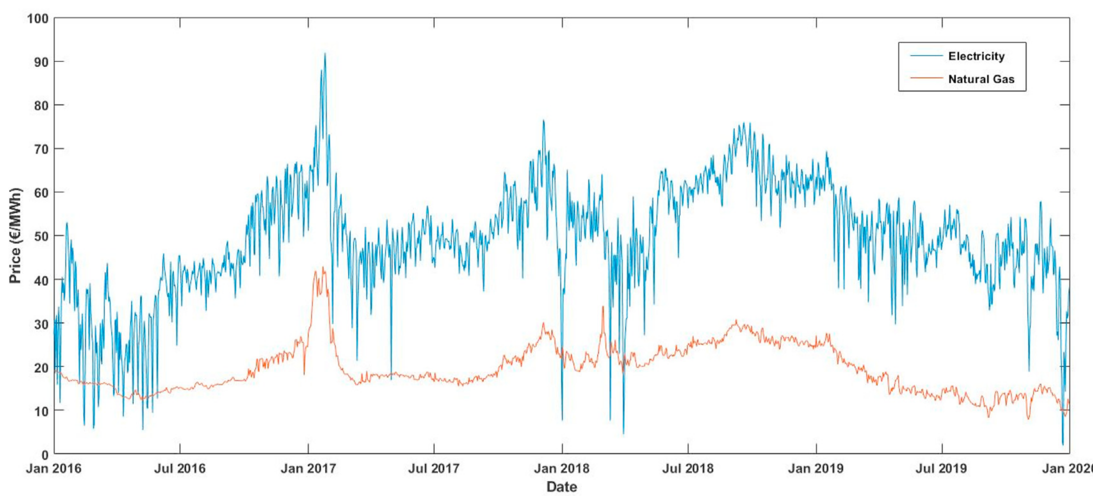

Fig. 5. Daily Spanish electricity and natural gas prices, 2016–2019.

Table 2
Correlations.

	Electricity	Natural gas	Carbon
Electricity	1.0000	–	–
Natural gas	0.6490	1.0000	–
Carbon	−0.1329	0.0260	1.0000

Table 2 shows the correlations between the three CSS components. These correlations influence past CSS values.

In this Section the CSS Ornstein-Uhlenbeck (OU) model is calculated (Abadie and Chamorro, 2009). The OU model is selected for its characteristics, including reversion to the mean and the possibility of obtaining negative values. The OU model is described by Equation (4).

$$dCSS_t = k^{CSS}(CSS^* - CSS_t)dt + \sigma^{CSS} dW_t^{CSS} \quad (4)$$

where CSS^* is the long-term equilibrium value (i.e. the level to which the current margin tends over time) and $k^{CSS}$is the reversion speed. σ^{CSS} is the instantaneous CSS volatility of the CSS margin and dW_t^{CSS} is the increment to a standard Wiener process. The OU is a mean reverting process that has two components: the first $k^{CSS}(CSS^* - CSS_t)dt$ is the deterministic part, which moves the CSS towards its long-term equilibrium value at a certain speed k^{CSS} t. This modelling of the deterministic part is consistent with the historical behaviour of CSS moving randomly below and above a mean value. This first part informs about the expected change in CSS in a time interval *dt*. The second component is the stochastic part This part enables values to be obtained that are different from those expected in simulations. The increasing or decreasing SLR caused by the stochastic part, in a short time dt, is proportional to $\sigma^{CSS}\sqrt{dt}$. Obtaining random values N (0,1), this stochastic part can be simulated. This form of model makes it possible to obtain negative values of CSS_t, as sometimes happens in the past data.

From this behaviour in the physical world, at time t = 0 the expected value for time t, which can be obtained for integration of Equation (4), is shown in Equation (5).

$$E_0(CSS_t) = CSS_0 e^{-k^{CSS}t} + CSS^*\left(1 - e^{-k^{CSS}t}\right) \quad (5)$$

Table 3
CSS simulated mean and percentiles (Ornstein-Uhlenbeck (OU) model).

Month 2020	CSS (€/MWh)				
		Expected		Actual	Difference
	Percentile 10%	Mean	Percentile 90%		Actual-Expected
January	1.78	7.10	12.36	9.16	+2.06
February	1.44	7.09	12.77	7.82	+0.73
March	1.67	7.12	12.57	3.75	−3.37
April	1.65	7.16	12.63	−4.15	−11.31
May	1.72	7.14	12.58	3.30	−3.84
June	1.42	7.03	12.63	9.54	+2.51

Using Equation (5), the parameter values and the starting value CSS_0, the expected CSS value at time t can be calculated easily.

Equation (6) is the discrete time version of Equation (5) used for calibration and simulation.

$$CSS_{t+\Delta t} = CSS^*\left(1 - e^{-k^{CSS}\Delta t}\right) + CSS_t e^{-k^{CSS}\Delta t} + \varepsilon_{t+\Delta t}^{CSS} = a^{CSS} + b^{CSS} CSS_t + \varepsilon_{t+\Delta t}^{CSS} \quad (6)$$

where $\varepsilon_t^{CSS} : N(0, \sigma_\varepsilon^{CSS})$. Once the regression parameters are calculated, the stochastic OU model parameters [19] can be obtained using Equations (7)–(9).

$$CSS^* = \frac{a^{CSS}}{1 - b^{CSS}} \quad (7)$$

$$k^{CSS} = -\frac{lnb^{CSS}}{\Delta t} \quad (8)$$

$$\left(\sigma^{CSS}\right)^2 = \frac{2\left(\sigma_\varepsilon^{CSS}\right)^2 \times lnb^{CSS}}{\Delta t\left[\left(b^{CSS}\right)^2 - 1\right]} \quad (9)$$

The estimated parameter values with 2016–2019 daily data are $CSS^* = 7.1151$; $k^{CSS} = 115.0652$ and $\sigma^{CSS} = 129.2938$ and the last value for 2019 is €7.19/MWh. Note that this last value is close to the CSS^* value and to the mean value for CSS shown in Table 1. These values show a process with a long-term value of 7.1151, which is very volatile, with $\sigma^{CSS} = 129.2938$ that behaves with a very high mean reversing speed. These values are compatible with the behaviour shown in Fig. 2.

4. Results and discussion

Using Equation (6) with random samples, 10,000 paths are generated on each of the 182 days of the first semester of 2020. The mean of each month is then calculated with the results shown in Table 3. Table 3 also includes the actual CSS values and the differences between actual and expected values. In the simulated matrix of 182 × 10,000 dimensions, 76.49% are positive and 23.51% negative, but all the daily and monthly means are positive.

In Table 3 the CSS figures for January, February and June are higher than expected while those for March to May are lower than expected. In April the actual CSS value is negative. In April the negative CSS value is €11.31/MWh less than expected. This coincides with the severest lockdown in the state of emergency in Spain between March 30, 2020 and 13 April, when non-essential activities such as construction and some industries were closed down. The actual value for April of -€4.15/MWh is also below the 10% percentile for that month, which is €1.65/MWh. Table 3 shows that the months with the worst CSS values compared to those expected are March to May, with the worst of all being April. June 2020 shows a CSS recovery.

Table 3 also shows minor differences between expected mean and percentile values for the first six months of 2020, this is mainly due to the correlation between electricity and natural gas prices, as shown in Table 2.

Table 4 shows the actual values of the three CSS components. Electricity, natural gas and carbon prices drop significantly from March. The net effect is a drop in the CSS, which became negative in April. In June the CSS value is higher than its expected mean. In some cases the drop in electricity prices is partially offset by the drop in natural gas prices.

The daily values for each path can be very different from the average, as illustrated in Fig. 6 with the first three daily simulated paths. These paths behave similarly to the real data for 2016–2019.

Fig. 7 shows the calculated mean monthly distribution of simulated values for April 2020, These mean monthly values are obtained with an accumulation of daily values for each path. There are 10,000 values for April 2020 represented in the histogram in Fig. 7. The negative actual value of -€4.15/MWh for April shown in Fig. 7 was highly improbable at the end of 2019, when the distribution of values was forecast for April 2020. The actual April CSS prices compared to the distribution in Fig. 8 show that real prices are not an extreme case of the simulated distribution: these prices are clearly below the 10% percentile as shown in Table 4.

These monthly mean distributions are drawn up with daily simulated data. It is also possible to show a distribution for one day. Fig. 8 shows the distribution for 04/30/2020, calculated with 10,000 simulated values.

A comparison of Fig. (7) and (8) according to expectations shows greater volatility in the simulated daily data than in the monthly data.

5. Conclusions

In this paper a distribution of monthly CSS values for the first six months of 2020 is calculated based on a stochastic model calibrated with information previous to the start of the Covid-19 pandemic, using the proposed stochastic diffusion model and comparing the actual CSS values with the expected values and percentiles.

The Covid-19 pandemic has affected all the world's economies and most sectors, including industry. Among other things it has reduced energy consumption and prices in wholesale markets. However in some cases, such as the CSS, this behaviour has affected both cost and income and the net effect is not always obvious.

This paper calculates the expected values and the distribution of simulated CSS values for the days of the first six months of 2020 taking the end of 2019 as a starting point. The monthly distributions and expected values are then calculated.

Table 4
The three CSS components.

Months	Components			Actual CSS (€/MWh)
	Electricity (€/MWh)	Natural gas (€/MWh)	Carbon (€/tonne)	
December 2019	33.80	12.02	25.33	1.17
January 2020	41.10	11.84	24.43	9.16
February 2020	35.87	9.86	24.09	7.82
March 2020	27.73	8.60	19.76	3.75
April 2020	17.65	7.38	20.11	−4.15
May 2020	21.25	5.39	20.00	3.30
June 2020	30.62	6.31	23.55	9.54

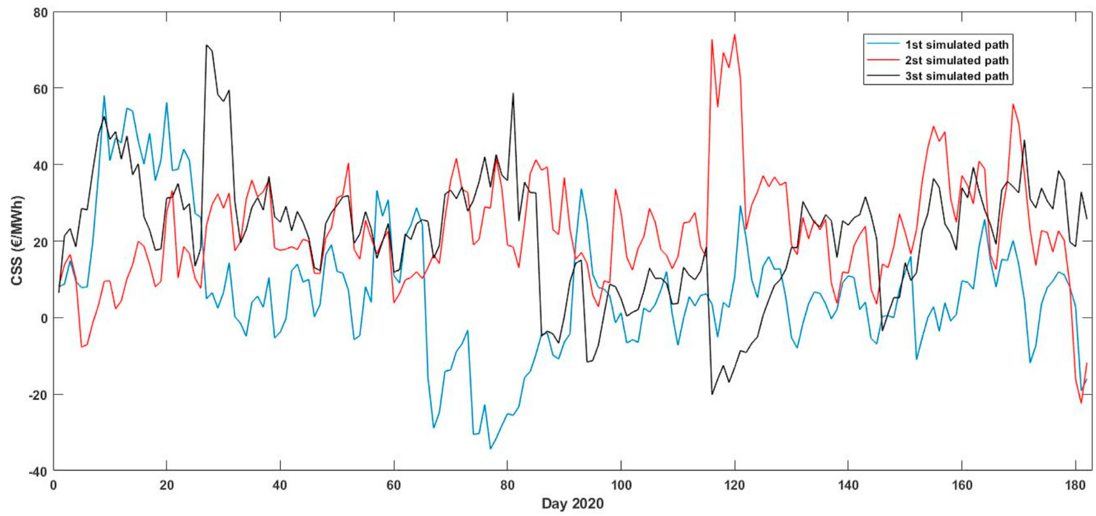

Fig. 6. First three daily CSS simulated paths.

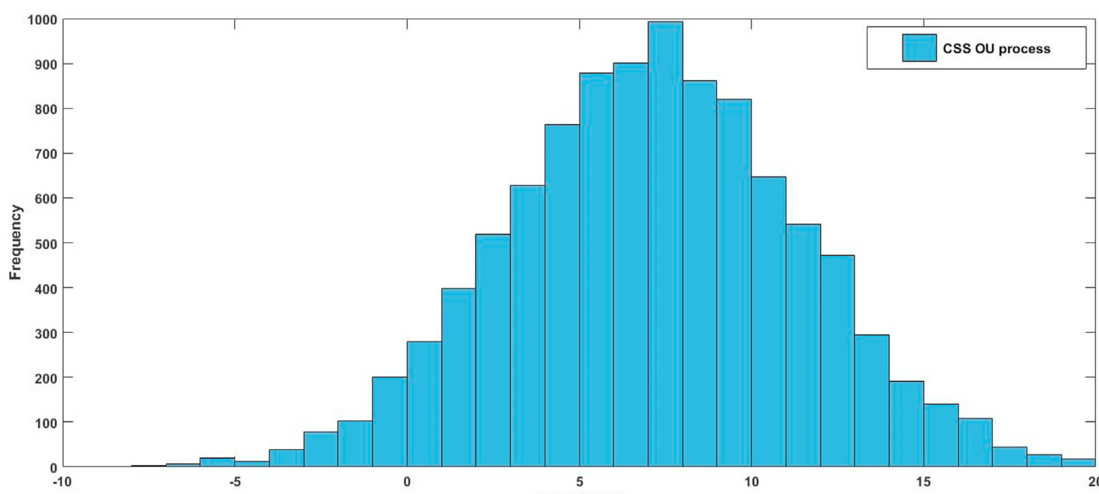

Fig. 7. Mean April distribution of expected values.

In this paper an OU model is designed and calibrated to predict the future behaviour of CSS values. The model is calibrated with Spanish daily electricity, natural gas and international carbon allowance quotes from 2016 to 2019, with the future simulations starting from the end of 2019. These simulations enable distributions of the simulated daily and monthly prices and consequently their expected value to be obtained. This model could be used to make similar estimates for other countries and for different natural gas power plant efficiency levels.

The CSS values are lower than expected for March–May 2020. This is mainly attributed to the Covid-19 crisis, although the mild temperatures in the northern hemisphere in the first months of the semester may also have had some influence. The month with the worst value is April 2020, when Spain increased the severity of its

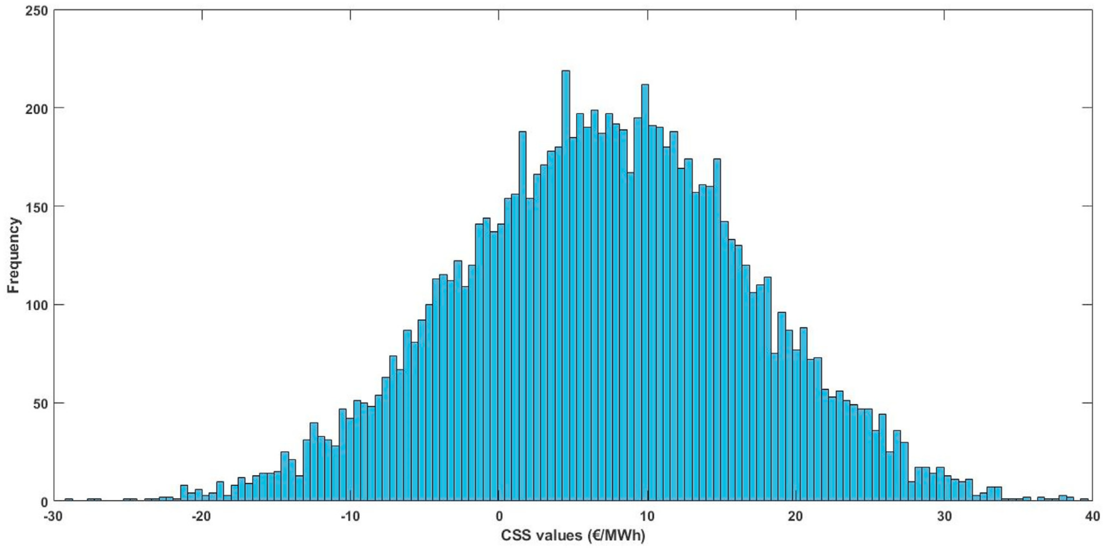

Fig. 8. Daily distribution of simulated values for 04/30/2020.

state of emergency from March 30, 2020 to 13 April, banning non-essential activities such as construction and some industries. In that month the mean of actual CSS prices was -€4.15 €/MWh, well down on the expected figure of €7.16/MWh and also far from the 10% percentile figure of €1.65/MWh. However, in April 2020 there are also positive CSS values on five days. The proposed model can easily be adapted to other countries with other electricity and natural gas prices, analysing the possibility of differentiated impacts for each country.

Three directions for future work are suggested: first, to analyse the impact of the Covid-19 pandemic on the Clean Spark Spread over a longer period such as a year or the time until the mass availability of a new vaccine; second, to analyse the expected CSS distribution using three correlated stochastic processes; and three, to study the impact of new and predicted CSS values on the profitability of Natural Gas Combined Cycle power plants and therefore their impact on the country's electricity generation mix. Future work could also analyse other countries using this methodology.

CRediT authorship contribution statement

Luis M. Abadie: Conceptualization, Methodology, Software, Writing - original draft, Writing - review & editing, Original draft preparation, Writing and Reviewing and Editing.

Declaration of competing interest

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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