Profitability Analysis of Spanish CCGTs under Future Scenarios of high RES and EV Penetration

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***Abstract*—Among conventional generation technologies in Spain, Combined Cycle Gas Turbines (CCGT) is the one that has experienced the largest development over the first decade of the 21st century. However, despite its promising future, multiple factors (such as the renewable generation increase, demand decline, adverse regulatory policies, etc.) have compromised their competitive position, reducing their capacity factor and undermining their financial viability. Because of those issues, electricity companies are giving up on new CCGTs investments, or even considering closing or mothballing some of their recently built plants. However, many still claim for the necessity of maintaining flexible backup technologies to cope with the variability of renewable energies, as a transition technology until energy storage or other future technologies emerge. This paper makes a profitability analysis of CCGTs in the Spanish electric power sector under different scenarios of RES penetration, carbon plants decommissioning, CO_2 emission costs and EV penetration.**

***Index Terms*-- Power generation mix, generation technologies, decarbonization, profitability, combined cycle.**

I. INTRODUCTION

Combined Cycle Gas Turbines (CCGT) have experienced the largest development among Spanish generation technologies over the first decade of the 21st century, with more than 25 GW installed between 2002 and 2011 (see Figure 1). The reasons of this spectacular growth were, among others:

- Ease of access to natural gas in Spain (good infrastructure of Liquefied Natural Gas and huge commercialization network).
- Social acceptance of this technology (in a context of lack of investment and lack of modernization of the Spanish generating mix).
- High operational flexibility of the plants.
- Fast construction project (around 2 years), with low building costs and moderate variable costs.

However, despite the growth of CCGT and its promising future, multiple factors have compromised their competitive position, reducing their capacity factor and undermining their financial viability, [1]. Among them are:

- Renewable generation (RG) grew from 5 GW up to 23 GW in the same 10 years period, fostered by Royal Decrees 436/2004 and 661/2007 with very advantageous remuneration mechanism for wind and solar technologies.
- Electricity consumption decline due both to the financial crisis and to the increasing efficiency.
- Regulatory policies, such as the quota to national coal, changing the merit-order function, [2].
- Constant reductions of capacity payments, with its aggravated regulatory instability.
- Introduction of new taxes to the production of energy, [3].
- Decrease of the international coal price, due to the cheaper American shale oil and shale gas, displacing American coal to other markets at more competitive prices, [1].

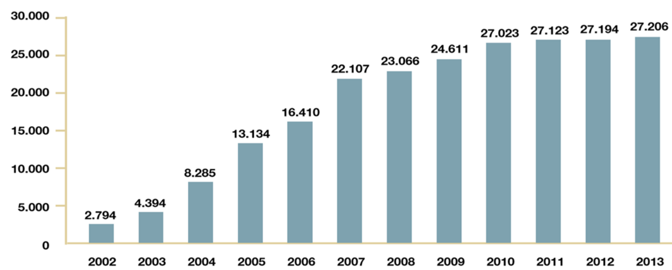

Figure 1: Evolution of CCTG installed capacity, [1]

Because of those issues, electricity companies are giving up on new investments in CCGTs, or even considering closing or mothballing some of their recently built plants, and by the end of 2016, the three major players in the Spanish generation sector decided not to invest in up to 5000 MW with already granted licenses, [4]. However, many claim that CCGT are still needed to provide flexible backup to deal with the variability of RG, at least as a transition technology until energy storage or other technologies emerge, due to their lower CO_2 emissions compared to coal plants. However, their profitability depends, among other, on: 1) the prices of natural gas; 2) the electricity wholesale market price, highly affected by other technologies such as RG or nuclear units (with priority in the pool due to the merit-order effect), with depressing effects on prices, [5]; and

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3) their actual operation, i.e. the hours of utilization, expected to decrease as RG increases, and the amount of start-ups and shutdowns, expected to increase.

CCGTs are now the main thermal conventional generation technology in Spain (see Figure 2, orange segments). While in the first years of the 21st century these units played a baseload role, in the last years they have become a backup technology, but still essential for the security of supply.

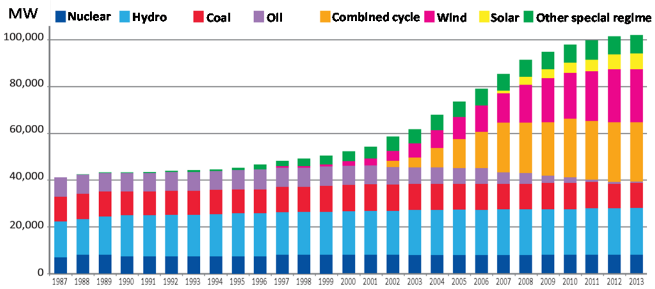

Figure 2: Evolution of generation installed capacity, [6]

With RG increasing, sufficient firm capacity is needed to generate when there is no sun and wind, to provide reserve to deal with RG variability and uncertainty [7], and to follow the (non-dispatchable) net demand ramps. However, recent research shows how RG are affecting the business case and viability of conventional firm power generation [8], and the need of long-term incentives for firm generation, since RG growth reduces their capacity factor, increases the intermittency of their usage and their cycling costs, pushes down the wholesale price, and therefore compromises their long-term profitability.

This paper makes a profitability analysis of CCGTs in the Spanish electric power sector under different scenarios of RES penetration, carbon plants decommissioning, CO_2 emission costs and EV penetration. Section II describes the methodology, section III the simulation scenarios, section IV the results and section V concludes.

II. METHODOLOGY

The profitability analysis is based on the Net Present Value (NPV) calculation:

$$NPV = \sum_{y=1}^{Y} \frac{FCF_y}{(1+WACC)^y} - FCF_0 \tag{1}$$

where Y is the total number of years, FCF_t is the cash flow in each year and FCF_0 the initial investment (cash flow in year 0 corresponding to 2018). While for assessing short-term security of supply a simple profit margin analysis can be enough, for long-term analysis, the NPV is needed to better capture the economic value of an asset for the entity that operates it. The rate at which the cash flows are discounted is equal to the firm's Weighted Average Cost of Capital (WACC), that represents the required rate of return expected by the investors, and can be assimilated to the opportunity cost of the firm. The WACC, set to 9%, is based on [7] and [8] that provides estimations for the electricity generation business (among others), at worldwide and European level. The cash flow for each year is computed as:

$$FCF = NI + Deprec - CAPEX \tag{2}$$

where *NI* is the net income, computed from Earnings Before Taxes (*EBT*), after subtracting the corporate tax *Tax* currently set at 25% [11]:

$$NI = EBT * (1 - Tax) \tag{3}$$

The *EBT* is computed subtracting, from the total revenue, the operative expenses ($OPEX$), the generation tax *genTax* of 7% applied to all generation units [3], a tariff *TPA* set to 0,5 €/MWh [12], and the depreciation *Deprec* (assumed linear, with 30 years of life spam for the CCGT and investments costs taken from [13]):

$$EBT = REVENUE - OPEX - genTax - TPA - Deprec \tag{4}$$

The revenue comes from the wholesale market (energy and ancillary services), estimated using the Spanish electric power system model CEVESA (see Figure 3 and later), and from the capacity mechanisms. Since capacity mechanisms are subject to a very high degree of regulatory uncertainty, they were ignored at this stage and estimated later as to turn the investment profitable (see section IV):

$$REVENUE = CP + \sum_{h} EP_h \cdot E_h + RP_h \cdot (RU_h + RD_h) \tag{5}$$

where CP is the capacity payment for the year considered, and EP_h, E_h, RP_h, RU_h and RD_h are the hourly variables corresponding respectively to the energy price, cleared plant production, reserve price and upward and downward cleared reserves.

The *OPEX* for a CCGT plant comes from the production costs, CO_2 emissions and startup and shutdown costs, estimated also with CEVESA:

$$OPEX = (SU + SD) \cdot n + VC \cdot \sum_{h} Em_h + EmP \cdot \sum_{h} Em_h \tag{6}$$

where SU and SD are the startup and shutdown costs, n is the number of startups-shutdowns, VC is the variable cost of the plant, E_h is the cleared production of the plant, and Em_h the hourly CO_2 emissions and its yearly price EmP.

In order to simplify the analysis, changes in net working capital (inventories, receivables, payables, etc.) have been disregarded for the capital assets forecast. The only capital assets variations considered are a capital expenditure at year 0 representing the current value of the plant (investment cost taken from [13]), and its linear depreciation.

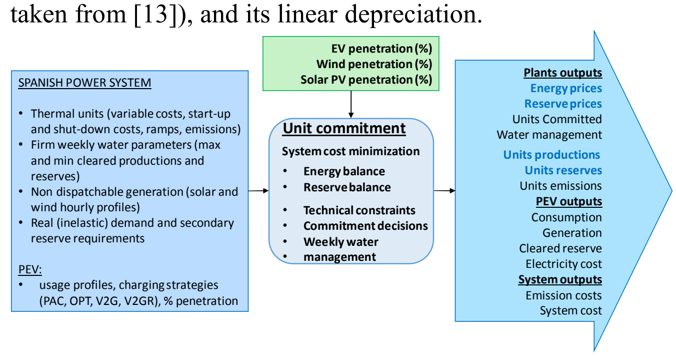

Figure 3: CEVESA, cost-minimization unit commitment model

As mentioned, revenues and operative expenses for CCGT plants have been estimated with CEVESA (Figure 3), a hydro, thermal and EV (electrical vehicles) unit-commitment model for the joint energy and reserve dispatch of the Spanish power system. For this analysis CEVESA was run to minimize the total system costs, including variable, startups, shutdowns and CO_2 emission costs for each thermal unit, [14], [15], [16].

To obtain more accurate electricity prices, the variable cost of the thermal generation units were estimated from their historical bids [17] following [18]. This work estimates the variable cost from the energy price, actual energy output, hour of the day and availability of the unit, based on the assumption that the wholesale market is fair and efficient, and that the market-clearing price represents the marginal cost of the most expensive unit cleared. They also assume that the units are producing at full load once the market price is above their variable cost, or otherwise the maximum output is affected by technical-economical restrictions, and the unit is not properly responding to the price signal. Under such assumption, the analysis returns a range of prices, and its median is chosen as the most representative price. The average accuracy $AvAcc$, computed as the number of times the market price is above the estimated variable cost and the plant is actually generating ($count_{up}$), plus the number of times the market price is below the estimated variable cost and the plant is not producing ($count_{dw}$), divided by total number of hours ($count_{tot}$) is used as a quality measure of the estimation:

$$AvAcc = \frac{count_{up} + count_{dw}}{count_{tot}} \tag{7}$$

This methodology was applied for the period 2009-2015, with a resulting $AvAcc$ of 80%, and an average estimated variable CCGT cost of 54,8 €/MWh. Although CEVESA captured well the energy price patterns, their average value was still below the real price for the same historical period (around 22 €/MWh below). It was then decided to use the estimated marginal cost of each plant for the merit order dispatch, but the final energy price was corrected by adding a markup derived from the historical data as in [19]. A statistical analysis showed that the markup was independent of the day of the month and on the weekday. A monthly markup, a linear regression (month, weekday, demand, hydropower production, and thermal production as inputs) and a neural network (with same inputs) were tested, and the regression model was finally the selected alternative based on the approximation errors and its low complexity. Figure 4 shows the final performance of the energy price estimation from the three models (including the markup) for January and December of 2015.

I. SCENARIOS

Even though the last EU agreement for 2030 targets [20], which increases renewable energy (RE) penetration from 27% to 32%, is not yet binding for every country, it could require investments in Spain of up to 80.000-100.000 M€ according to APPA (Asociación de Empresas de Energías Renovables) [21]. Given that most of CCGT plants in Spain were installed between 2002 and 2006, and assuming a lifespan of 30 years [22], most of such plants will have reached the end of their life by 2035. Therefore, the present analysis covers scenarios happening in the period 2018-2035.

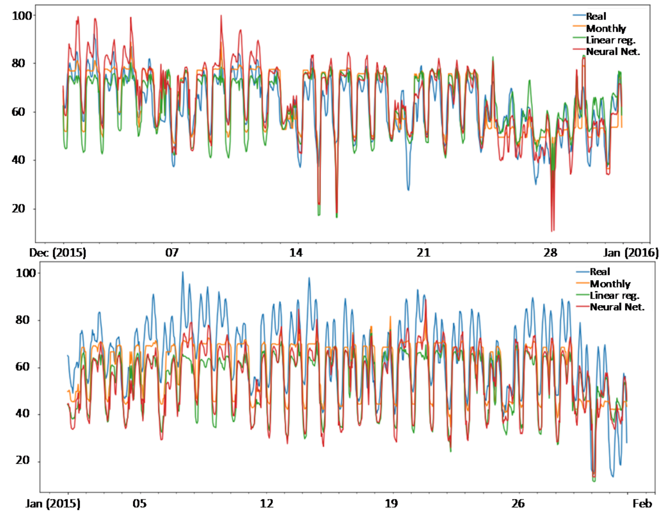

Figure 4: Real and estimated energy prices (€/MWh), Jan and Dec 2015

To prepare such scenarios, apart from the EU strategic roadmap [23]–[25], several reports from different consulting firms [26], energy institutions [27], [28], energy sector companies [29], and regulatory bodies [30], [31] have been considered. Three main scenarios were designed: Social Stagnation, Sustainable Growth and Advanced Technological Development. The outcome of the scenarios design (Table I) is a set of parameters for 2035 for each scenario, with a development path for each parameter from their current 2018 values to the proposed 2035 values. Due to computational time constraints, only some intermediate scenarios were simulated, with the remaining values estimated via interpolation.

TABLE I. PARAMETERS IN 2035 FOR THE DESIGNED SCENARIOS

Parameters	***Base***	***SS***	***SG***	***ATD***
Demand (TWh)	255	280	310	360
EV penetration (%)	0%	10%	10%	20%
Solar cap. (MW)	4.059	16.000	38.000	45.000
Wind cap. (MW)	21.017	34.000	38.000	40.000
Nuclear cap. (MW)	7.866	5.317	6.317	7.117
CO_2 price (€/tCO_2)	12,9 €	30 €	50 €	70 €

A. Social Stagnation (SS)

This scenario (Table I, entry SS) is inspired from two scenarios of [27], with some considerations from [23]. It corresponds to a deceleration context, with growing inequalities affecting the middle class, leading to political instability that hinders the successful implementation of environmental policies and support schemes for renewables and new technologies, reducing current investment trends.

EU renewable energy targets that translate into 16 GW of solar capacity, and 34 GW of wind capacity are not met. Social pressure forces nuclear plants closure (out of the system by 2050) with 5 GW remaining by 2035. The energy mix is less decarbonized than the one proposed by the EU, where economic recession is considered. Transport electrification limits to passenger vehicles, and heavy transport still depends on fossil fuels, so there is only 10% EV penetration in the total fleet. Finally, the small increase in demand, combined with the investment in renewables, relaxes CO_2 emissions restriction, resulting in a CO_2 emission shadow price of around 30 €/tCO_2.

B. *Sustainable Growth (SG)*

This scenario (Table I, entry SG) assumes a sustainable development as a consequence of current policies and trends. No major changes or disruptions occur, and EU targets are met by 2030, although 2050 targets are not so likely to be met.

Following [27], electric demand grows at an annual rate of 1.3%, driven by an electrification of heating and cooling systems, and by an EV penetration that reaches 10%, but heavy transport is still dependent on fuel. The growth in electricity consumption is partially compensated by a decrease in the household consumption due to self-consumption and efficiency measures. The resulting total annual demand is around 310 TWh.

Installed wind capacity almost doubles current value, reaching 38 GW by 2035, but main RG growth corresponds to solar capacity that jumps from around 4 GW to 38 GW. Wind and solar generation alone contribute to up to 47% of the energy consumption by 2035, more than enough to meet EU targets. Regarding nuclear energy, apart from Garoña, another plant is assumed to be decommissioned by 2035, leaving 6.3 GW of installed capacity. This reduction in the base load capacity, combined with the increase in electricity demand and tighter CO_2 restrictions, raises CO_2 emission price to 50 €/tCO_2, as assumed in the EU's *Ten Year Network Development Plan* [32].

C. *Advanced Technological Development (ATD)*

This scenario (Table I, entry ATD) presents a more disruptive outlook, in which Research & Development is clearly supported by the political agenda of developing countries, reaching considerable cost reductions in RG, batteries and EV. The values presented have been borrowed from [27] and [28]. Advances in autonomous vehicles boost EV penetration, which reaches 20% of the total fleet. Heavy transport experiments a modal switch to train and electric trucks, contributing to the growth in electricity demand.

A massive electrification of heating and cooling systems is another driver of demand growth, together with the industrial consumption increase derived from the economic development. However, these increases are compensated by important increases in efficiency, leading to a final demand of 360 TWh. Wind and solar capacity end in 40 and 45 GW, respectively, contributing to supply around 45% of the energy demand by 2035. EU targets are also meet in this scenario, in which strong restrictions to CO_2 emissions make the shadow price go up to 70 €/tCO_2 (by 2050 such price is expected to reach 500 €/tCO_2). Social opinion pivots towards a more favorable position regarding nuclear energy, and political compromises allow the current 7.1 GW to extend their useful life beyond 2035, and even start new projects for 2050.

II. Results

For simplicity, results focus only on Santurce IV CCGT plant, considered representative for having its parameters closer to the median of all CCGT parameters (see Table II).

TABLE II. SANTURCE IV CCGT PLANT PARAMETERS

Parameter	***Value***
Capacity	396,4 MW
Year of construction	2005
Investment	180 M€
Age	13 years
Current value (linear depreciation)	102 M€
Estimated remaining life	17 years
Start-up cost	45.319 €
Shutdown cost	6.037 €
Estimated variable cost	43,8 €/MWh
CO2 emissions	0,391 tCO2/MWh

Two red flags need to be carefully assessed: negative NPV and negative cash flows throughout the analyzed period. The first one means that the market is sending the signal that a CCGT plant is not able to recover the investment in the long term, while the second one means that the plant's operating costs are higher than the generated revenue. A sensitivity analysis has also been conducted over the capacity payments to assess at which point the red flags disappear in each scenario. Results for each scenario are collected in Table III.

TABLE III. NPV, CASH FLOWS AND CAPACITY PAYMENTS ANALYSIS

Capacity Payments	***SS***		***SG***		***ATD***	
	NPV (M€)	Neg. CF	NPV (M€)	Neg. CF	NPV (M€)	Neg. CF
0 €	-118,9	Yes	-181,5	Yes	-266,0	Yes
24.000 €	-44,0	No	-105,6	Yes	-189,9	Yes
41.000 €	0,0	No	-56,0	Yes	-139,0	Yes
61.625 €	49,9	No	0,0	Yes	-80,0	Yes
77.600 €	88,6	No	41,0	No	-36,0	Yes
90.950 €	120,9	No	74,0	No	0,0	Yes
172.500 €	318,3	No	271,4	No	207,7	No

The results show a clear pattern: as the penetration of RG increases, both the long and short-profitability of the CCGT plants decrease. The combination of increased CO_2 emission price (which reduces the operating margin of the plant) and higher RG penetration (which reduces the utilization rate) lead to remarkable decreases in their profitability, and large sums of capacity payments (ranging from 41 to 91 k€) are needed in order to guarantee future back-up capacity.

Therefore, the findings suggest that, with the current situation in Spain (with the availability payment being withheld and the investment incentive payment being already paid, or about to be) most plants could face scenarios in which their operative income is not able to cover their variable and annual fixed costs, and are hence in danger of being retired prematurely.

III. Conclusions

Decommissioning or mothballing are the main alternatives when a power plant's revenues are not sufficient to cover its variable cost and annual fixed cost. However, since investment expenses are sunk costs, such plants are kept in the market even if they do not manage to recover their investments, as long as their cash flows are positive. This work suggests that most CCGT plants could face scenarios in which their operative income would not cover their variable and annual fixed costs, risking their premature withdrawal from the mix.

This study reinforces the necessity of introducing proper capacity mechanisms to hedge against the uncertainty around the CO_2 emission price, the nuclear capacity and the investment costs of batteries and RG, able to guarantee some additional revenue between 41 and 91 k€/MW/year, and flexible enough for the regulator to adapt it to the short-term back-up requirements, so that the system does not incur in large over costs from improper planning. Those measures pass through the design of robust capacity markets, as the ones recently approved by the EU in countries such as UK, Germany, Italy, or France.

This analysis, however, focused only on the profitability of the CCGT plants, and has not studied alternatives such as hydro production as back-up capacity. Even though, with the assessed scenarios there appears to be an immediate cause for alarm in terms of guaranteeing the profitability of such back-up capacity, it is also true that the Spanish electricity market is in a situation of overcapacity. In this sense, the real amounts of firm capacity and reserves should be assessed, considering that, by 2035, almost all the CCGT units currently installed in Spain will have reached the end of their technical lifetime, but considering also the improvements of the interconnection with the European system and the European reserves coordination mechanisms currently in progress.

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