DEGREE IN INDUSTRIAL TECHNOLOGY ENGINEERING

BACHELORS`S DEGREE FINAL PROJECT

Profitability analysis of electricity generation technologies based on the CEVESA market model

Author: Juncal Guerrero Rodríguez

Supervisor: José Villar Collado

Co-Supervisors: Fco. Alberto Campos Fernández

Salvador Doménech Martínez

Madrid

July 2021

I declare, under my own responsibility, that the Project submitted under the title

PROFITABILITY ANALYSIS OF ELECTRICITY GENERATION TECHNOLOGIES BASED ON THE CEVESA MARKET MODEL

at the ETS of Engineering - ICAI of the Comillas Pontifical University in the academic year 2020-2021 is of my authorship, original and unpublished and has not been previously presented for other purposes. The Project is not a plagiarism of any other, either in whole or in part, and the information that has been taken from other documents is duly referenced.

THE AUTHOR:

Juncal Guerrero Rodríguez

Fdo.: Juncal G ……………………………. Fecha: 8/ 07/2021

The delivery of the project has been authorised

THE SUPERVISOR:

José Villar Collado

VILLAR COLLADO JOSE - 00818527A Digitally signed by VILLAR COLLADO JOSE - 00818527A Date: 2021.07.09 09:38:38 +01'00'

Fdo.:………………………… Fecha: 8/07/2021

CO-SUPERVISORS:

Fco. Alberto Campos Fernández

CAMPOS FERNANDEZ FRANCISCO ALBERTO - 11836144E Firmado digitalmente por CAMPOS FERNANDEZ FRANCISCO ALBERTO - 11836144E Fecha: 2021.07.09 10:32:45 +02'00'

Fdo.:………………………… Fecha: 8/07/2021

Salvador Doménech Martínez

Fdo.:………………………… Fecha: 8/07/2021

COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

BACHELOR`S DEGREE IN ENGINEERING FOR INDUSTRIAL TECHNOLOGIES

BACHELORS`S DEGREE FINAL PROJECT

PROFITABILITY ANALYSIS OF ELECTRICITY GENERATION TECHNOLOGIES BASED ON THE CEVESA MARKET MODEL

Author: Juncal Guerrero Rodríguez

Supervisor: José Villar Collado

Co-Supervisors: Fco. Alberto Campos Fernández
Salvador Doménech Martínez

Madrid

July 2021

COMILLAS PONTIFICIAL UNIVERSITY
ICAI SCHOOL OF ENGINEERING
DEGREE IN ENGINEERING IN INDUSTRIAL TECHNOLOGIES

PROFITABILITY ANALYSIS OF ELECTRICITY GENERATION TECHNOLOGIES BASED ON THE CEVESA MARKET MODEL

Author: Guerrero Rodríguez, Juncal.

Supervisors: Villar Collado, José

Campos Fernández, Fco. Alberto

Doménech Martínez, Salvador

Collaborating Entity: ICAI – Comillas Pontificial University & INESC TEC- Institute for Systems and Computer Engineering, Technology and Science

PROJECT SUMMARY

Abstract - The peninsular electricity system has significantly increased the presence of renewable energies, motivated by the objectives set by the European Commission with a view to achieve total decarbonisation by 2050. To contribute to this goal, each country has drawn up a National Energy and Climate Plan for the period from 2021 to 2030. Due to the intermittent nature of renewable energy generation, the Spanish and Portuguese NECP assigns existing combined cycle power plants the role of back-up power. This study analyses the profitability of today's most developed renewable technologies (wind and solar) and combined cycle power plants, which are indispensable in the transition to secure electricity supply. To this end, CEVESA, a model that simulates the long-term planning and operation of the Iberian electricity system and a financial model (developed in this thesis) are used together. Two possible scenarios for the evolution of the NECP are evaluated, allowing results to be obtained regarding the viability of future investments and current back-up technologies.

Keywords−renewable energy, decarbonization, electricity market, profitability analysis, investments

I. INTRODUCTION

According to Spanish Electricity Grid annual report, the year 2020 saw an all-time record for energy production from renewable sources. Specifically, wind and solar photovoltaic experienced a historical maximum of generation with a percentage of 21,9% and 6,1%, respectively of the total energy produced in the national territory. In Portugal, according to figures published by REN (Redes Energéticas Nacionais), 61.7% of energy production in 2020 came from renewable sources.

On contrast, conventional technologies such as coal have made little contribution to meeting demand due to the small number of plants that remain in operation [1]. Companies have decided to close these plants due to their lack of competitiveness compared to renewables and combined cycle plants.

There are two fundamental issues that threaten the future of conventional technologies (coal, combined cycle and nuclear): the economic profitability of this type of power plants and the environmental damage caused by their operation.

Given that the income received by the different technologies corresponds to the amount of energy they generate each day and the daily price of electricity, it is possible that conventional plants do not recover all their investment costs through the daily market.

At present, combined cycle plants play a fundamental role in ensuring the continuity and security of electricity supply thanks to their flexibility and high efficiency. In fact, in the draft of the "National Integrated Energy and Climate Plan 2021-2030" (PNIEC 2021-2030) the installed capacity of this technology remains practically constant [2]. This document establishes the basis for a strategic plan towards a future system of efficient, emission-free generation with a predominant volume of renewable energies. The issue is that by 2050 this type of technology may disappear according to European strategies.

This project analyses the profitability of the different generation technologies through a financial model integrated into CEVESA environment and using its results from the simulation of the Iberian electricity market (MIBEL). CEVESA is a model shared by the Technological Research Institute (IIT) of the Pontifical University of Comillas and the Institute of Systems and Computer Engineering, Technology and Science of the University of Porto (INESC TEC) ([3],[4], [5]).

For this purpose, a set of scenarios will be designed based on the current decarbonization plans included in the PNIEC of Spain and Portugal and a pessimistic alternative. The financial module will be designed to calculate the profitability of the generation technologies based on the long-term operation and investment results provided by CEVESA for each simulation scenario.

Both models will enable to assess the influence of renewables on the profitability of conventional technologies through the recovery or not of investment costs according to the different scenarios designed.

II. METHODOLOGY

II-A. Financial model

Firstly, an extensive literature review and different economic methods have been evaluated to analyse the profitability of the different energy technologies. Finally, the financial model will be composed of the most common profitability indicators when valuing a project, such as NPV, IRR, LCOE, IP and TLCC.

Before proceeding to the calculation of the above parameters, it is necessary to obtain the annual cash flows for each technology. For this purpose, it was decided to apply a Discounted Cash Flow (DCF) model, commonly used to appraise companies based on its expected future Unlevered Free Cash Flows (UFCF). Three main types of cash flows are considered when calculating the UFCF: cash inflows, cash outflows and cost of capital (CAPEX).

Cash inflows represent income occurring in a specific period from operating activities. Depending on the type of generation unit, different sources of revenues were considered (market price and/ or ancillary service).

Cash outflows are expenses derived from the operation of the different technologies and typically include operation and maintenance (O&M) costs, fuel costs, personnel, insurance, etc. Fees paid to the government are also included in this section. Debt or financial costs are not considered as the capital structure of the company or project is ignored in the calculation of the UCFC.

Depending on the country in which the generation units operate, they have to pay a number of fees for performing their activity and obtaining economic benefits. In this paper, in the case of the Spanish units, a 7% IVPEE will be assumed, a 30% corporate tax for conventional thermal power plants and 25% for the rest of the units. Portuguese plants will face a corporate tax of 21%.

Capital expenditure is the investment in capital or fixed assets that a company makes to acquire, maintain, or improve its non-current assets. Typically, in energy projects this refers to the initial purchase of plant and equipment that takes place at the start of the project.

II-B. Simulation market model

Once the profitability indicators that constitute the financial model were determined, the way to adjust it to the CEVESA market model was designed.

In this study, revenues, operating and production costs for each generation unit and technology represented were obtained directly from CEVESA as outputs. Specifically, the model provides these data by unit in the case of thermal power plants and hydroelectric plants. In reference to new investment technologies, data is provided by type of technology (wind, solar photovoltaic, solar thermal and cogeneration, among others).

In this analysis CEVESA is solving two problems: investment and then operation. When carrying out the simulation in CEVESA to solve the investment problem in both scenarios, a restriction on CO2 emissions stipulated by the European Union was included, whose reference appears in the following document [5]. This constraint forces investments in renewables to be high in order to reduce thermal generation. Therefore, the results of new investments in addition to cost minimization and demand coverage take into consideration the emission limitations.

Considering that the emissions constraint has no safety coefficient, it is very likely that, in operation mode, the generation technologies are producing at the limit of their capacity. This situation causes that in certain hours the model provides a marginal cost (assumed equal to the market price) between the present value and the cost of the energy not supplied. Currently, in the model, the price of energy not supplied corresponds to 1000 €/MWh. In the real market, the cost is limited to 3000 €/MWh although until recently the limit price was 180 €/MWh, so the amount considered in CEVESA is reasonable.

The results obtained in the two scenarios reflect episodes of high prices from 2035 onwards, which will be close to the price of energy not supplied.

III. RESULTS

At this point, the CEVESA market model, and the financial model explained in the previous section will be applied to each to each of the scenarios mentioned above. The data collected in the NECPs correspond to the period 2021-2030 but in order to obtain a more reliable financial analysis, it has been chosen to extend the analysis interval to 2050. Therefore, each input parameter of the CEVESA market model has values until 2050. Due to time constraints, it has been decided to reduce the simulation years to intermediate years and then estimate the remaining values by linear interpolation.

The analysis of the results has focused on new investments in wind and solar photovoltaic energy and on the existing combined cycle plants that will have to operate to ensure electricity supply.

III-A. NECP scenario

The parameters used as inputs to the CEVESA model are specified below in

two tables, one for each country. The base year refers to the initial year of the analysis, which in this case is 2020. The values for the year 2050 have been obtained by extrapolating the figures of previous years.

Table I. Parameters for the Spanish NECP scenario in 2050.

Parameters	Estimated values	
	Base (2020)	**2050**
Wind capacity (GW)	28.033	67.333
Solar capacity (GW)	9.071	56.181
Battery capacity (GW)	0	19.5
Total expected demand (GWh)	250638.86	413421.37
Interconnection capacity (ESP-POR) (MW)	2000	4700
CO_2 prices (€/ton)	15	48
API2 prices (€/ton)	47	47
TTF prices (€/MWh)	9	9

Table II. Parameters for the Portuguese NECP scenario in 2050.

Parameters	Estimated values	
	Base (2020)	**2050**
Wind capacity (GW)	5,4	23.3
Solar capacity (GW)	2	23
Battery capacity (GW)	0	0
Total expected demand (GWh)	50648.076	83542.5
Interconnection capacity (POR-ESP) (MW)	2000	4000
CO_2 prices (€/ton)	15	48
API2 prices (€/ton)	47	47
TTF prices (€/MWh)	9	9

The results show that during the years covered by the NECP, the cumulative installed capacity of renewable energies has remained constant. New investments take place from 2030 onwards (Figure 9). This is due to the continuous increase in demand and the increase in CO2 and fuel costs that result in a lower production of combined cycle plants (Figure 10). Both the installed capacity and production of wind and solar power continue to grow until 2050. In addition, around 2040 the last nuclear power plant in Spain will be shut down, further encouraging investment in renewables.

Results and figures of Portugal show similar trends.

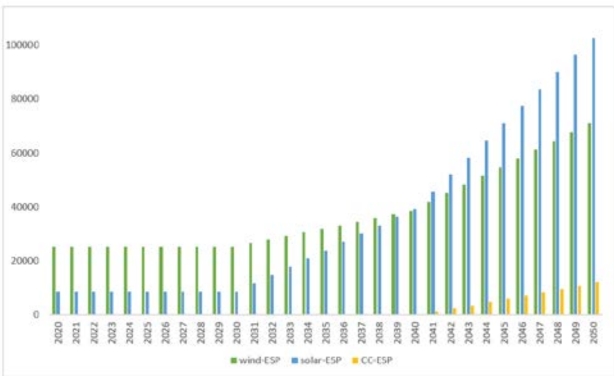


Figure 9: Evolution of accumulated installed power in Spain under the INECP scenario (MW).

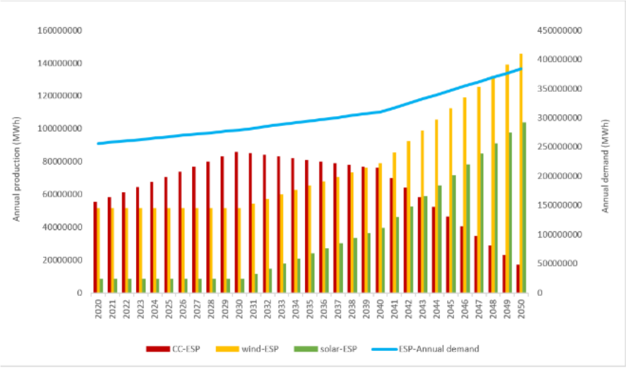


Figure 10: Annual production technologies and annual demand in Spain under the INECP scenario (MWh).

Considering that the restrictions on emissions when running CEVESA provide higher revenue values through the market, the profitability of renewable energies is guaranteed due to the high net present values and IIR obtained.

The situation of the combined cycle power plants is more complex and diverse, as in the last few years of analysis their production has decreased significantly, which directly affects the income they receive. However, under this scenario they are still profitable.

Finally, it is worth noting the results found for each LCOE technology, which are very close to the ranges estimated by the American investment bank Lazard.

	LCOE
ESP-wind	27,215
ESP-solar	23,639
ESP-CC	60,132
POR-wind	21,543
POR-solar	16,128
POR-CC	49,927

Table III. LCOE results under the NECP scenario (€/MWh).

III-B. Pessimistic scenario

The input parameters of this scenario are as follows:

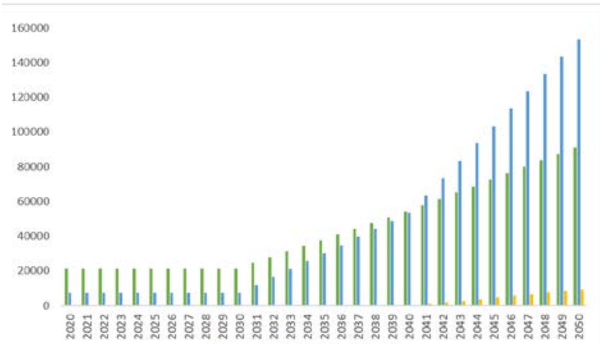
Parameters	**Estimated values**	
	Base (2020)	**2050**
Wind capacity (GW)	23.828	54.683
Solar capacity (GW)	7.710	45.204
Battery capacity (GW)	0	14.025
Total expected demand (GWh)	251137.152	484518.384
Interconnection capacity (ESP-POR) (MW)	1500	3525
CO_2 prices (€/ton)	15	58
API2 prices (€/ton)	57	57
TTF prices (€/MWh)	19	19

Table IV. Parameters for the Spanish PESS scenario in 2050.

Parameters	**Estimated values**	
	Base (2020)	**2050**
Wind capacity (GW)	4.59	19.805
Solar capacity (GW)	1.7	19.55
Battery capacity (GW)	0	0
Total expected demand (GWh)	50748.768	97909.492
Interconnection capacity (POR-ESP) (MW)	1950	3000
CO_2 prices (€/ton)	15	58
API2 prices (€/ton)	57	57
TTF prices (€/MWh)	19	19

Table V. Parameters for the Portuguese PESS scenario in 2050.

In this scenario the installed capacity of renewable energies is lower as it represents a pessimistic evolution of the NECP (Figure 18). The interannual growth in demand is greater than in the base case, so the production of combined cycle plants is higher (Figure 19). This situation favours the profitability of the plants, as the more hours they remain in operation, the more income they receive.



As in the previous scenario, new investments are made from 2030 onwards, and given that demand growth is considerable in the following years, so is the installed capacity. In fact, in the year 2050, the figures achieved for installed capacity are higher than those of the base case to ensure electricity supply. In Portugal, the situation is similar.

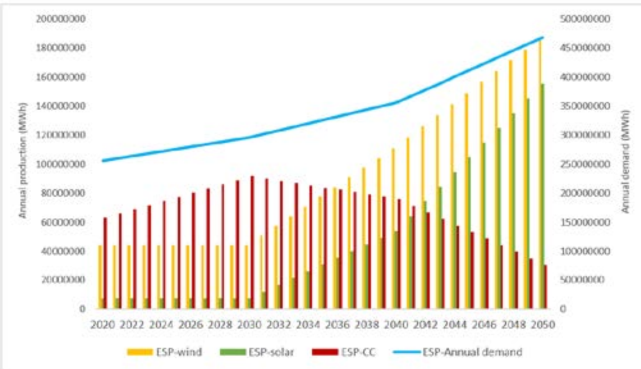


Figure 19: Annual production technologies and annual demand in Spain under the pessimistic scenario (MWh).

Regarding the LCOE values, the results are quite similar to those of the previous scenario.

	LCOE
ESP-wind	27,067
ESP-solar	22,819
ESP-CC	61,751
POR-wind	21,275
POR-solar	16,434
POR-CC	56,912

Table V. LCOE results under the pessimistic scenario (€/MWh).

Comparing the results of the pessimistic scenario with those of the baseline one, it can be seen that the parameters are more favourable in terms of viability (higher values of NPV, IIR and PI). Therefore, the increase in demand growth that forces the plants to generate more electricity has a positive influence on their revenues.

IV. CONCLUSIONS

This analysis has focused on determining the profitability of new investments in renewable energies (wind and solar photovoltaic) and existing combined cycle power plants under a scenario of emission restrictions. This simulation mode emphasises investments in renewables to replace conventional generation. This situation can lead to periods when demand is not met, and the marginal cost of the market approaches the price of the energy not supplied. These values, which are equivalent to the market price of the technologies, are high, resulting in increased revenues. Therefore, the profit margin of the technologies is higher than it would be in a scenario without emission restrictions.

Therefore, the results achieved do not accurately represent reality, but they can give an idea of the economic situation of the technologies under a situation of emission restrictions. Hence, future analyses should try to provide values that are more in line with real market prices in order to be able to define more rigorously the viability of the different generation units.

To summarise, the results of the study show the high profitability of renewable technologies in both scenarios. The biggest problem is for combined cycle power plants, as not all of them have positive cash flows. In the pessimistic scenario, the lower installed capacity of renewables together with a higher interannual change in demand contributes to an increase in production by gas-fired plants. This situation results in higher profitability of back-up technologies. It is clear that in such a scenario with high market prices, most CCGT plants are able to recover their costs. The question arises whether in a scenario without restrictions on CO2 emissions and with lower market prices they could also make a profit and not jeopardise security of supply. Consequently, it is important that combined cycle plants can participate in the capacity market so that they can receive incentives based on their availability, as renewables already do.

V. BIBLIOGRAPHY

[1] «Avance del Informe del sistema eléctrico español 2020 | Red Eléctrica de España». https://www.ree.es/es/datos/publicaciones/informe-anual-sistema/avance-del-informe-del-sistema-electrico-espanol-2020 (accedido may 26, 2021).

[2] «Los ciclos combinados y la eólica en el mix de electricidad español - AleaSoft Energy Forecasting». https://aleasoft.com/es/ciclos-combinados-eolica-mix-electricidad-espannol/ (accedido may 26, 2021).

[3] S. D. Martinez, Fco. A. Campos Fernandez, M. R. Abbad, y J. villar Collado, «Joint Centralized and Distributed Electricity Generation Expansion in a Decarbonized Scenario: The Spanish Case», en *2018 15th International Conference on the European Energy Market (EEM)*, jun. 2018, pp. 1-5. doi: 10.1109/EEM.2018.8469911.

[4] J. Villar, E. Salas, y A. Campos, «Combined Penetration of Wind and Solar Generation with Plug-in Electric Vehicles», *Energy Procedia*, vol. 106, pp. 59-72, dic. 2016, doi: 10.1016/j.egypro.2016.12.105.

[5] R. Castañón, A. Campos, S. Doménech Martínez, y J. Villar, «An Electricity Generation Expansion Model with ICEV and PEV Investments», jun. 2018, pp. 1-5. doi: 10.1109/EEM.2018.8469772.
Geogr., n.º 130, Art. n.º 130, sep. 2018, doi: 10.4000/mediterranee.10113.

Contents

INTRODUCTION

The increase in electricity generation from renewable energies is becoming more remarkable every year worldwide. Specifically in Spain and Portugal, the penetration of emission-free technologies is growing steadily.

According to Spanish Electricity Grid annual report, the year 2020 saw an all-time record for energy production from renewable sources. Specifically, it accounted for a 44% of total power system generation compared to 37.5% in 2019. Among the types of renewable energies, wind and solar photovoltaic experienced a historical maximum of generation with a percentage of 21.9% and 6.1%, respectively of the total energy produced in the national territory.

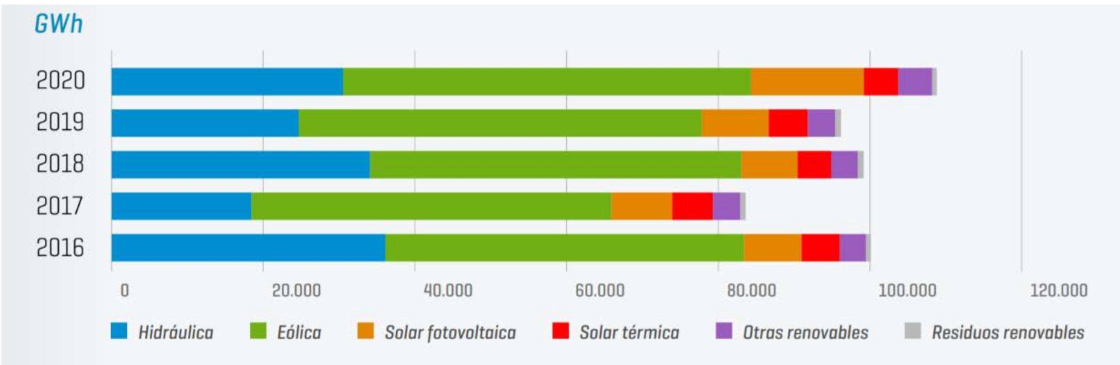


Figure 1: Evolution of peninsular renewable electricity generation. Source: REE.

In contrast, non-renewable energy generation from coal and combined cycle power plants has been lower than in previous years. Since these technologies pollute when burning the fuel, they use to produce energy, the reduction of their production has led to a 27.9% decrease in CO_2 emissions.

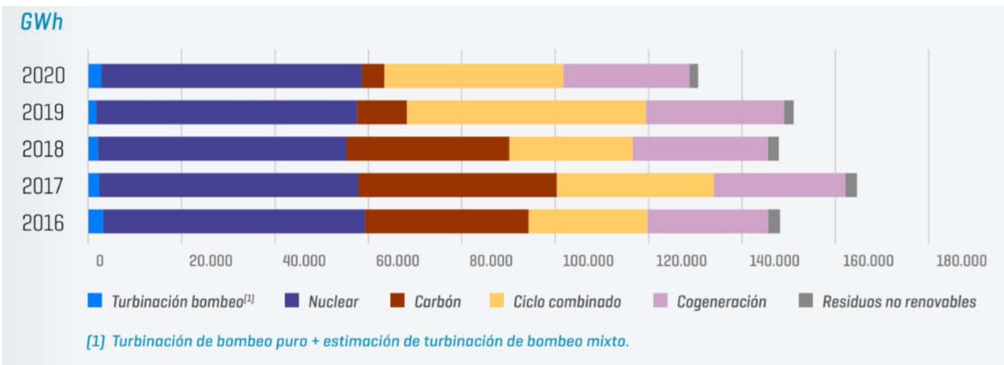


Figure 2: Evolution of peninsular non-renewable electricity generation. Source: REE.

As most of the electricity production has come from renewable sources, 69% of the Spanish electricity demand has been covered with this type of technologies: wind (22.2%), hydro (12.6%) and solar photovoltaic (6.1%). With respect to fossil fuel technologies, there has been a considerable decrease in the contribution of coal power plants to the Spanish electricity system which have reached a record minimum (2%). This has been due to the small number of plants that remain in operation [1]. In June 2020, seven thermal power plants were decommissioned and three more are scheduled to do so this year [2]. The main reasons why Spanish companies have decided to close plants are their lack of competitiveness compared to renewables and combined cycle plants, the absence of improvement prospects and changes in electricity market conditions [3]. However, these are not the only conventional technologies that have suffered a decline in their share of the energy mix. Combined cycle power plants have provided a coverage of 15.8% in 2020 versus a 21.1% in 2019. The decrease in electricity demand due to the Covid-19 pandemic together with the increasing penetration of renewable energies may be the main causes.

Finally, nuclear power generation remained the same as in previous years with a percentage of 23% electricity demand coverage [1].

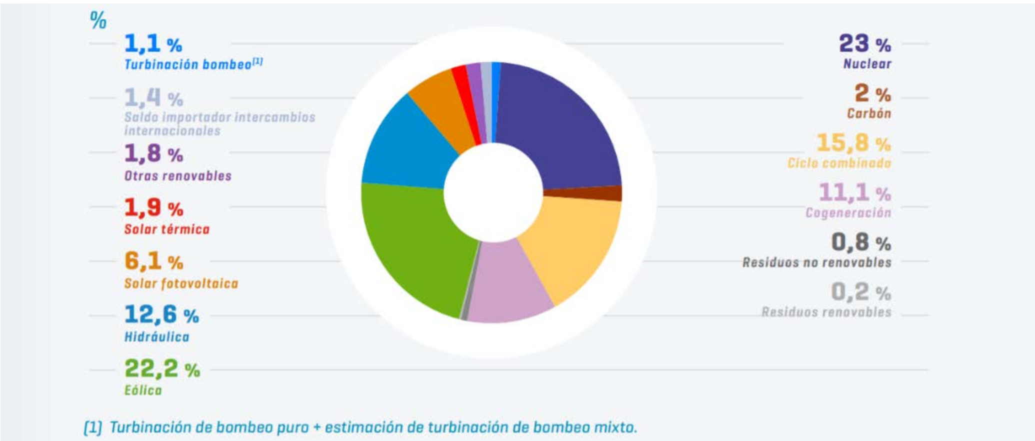


Figure 3: Coverage of peninsular electricity demand. Year 2020. Source: REE

Referring to the characteristics of electricity generation in Portugal and according to figures published by REN (Redes Energéticas Nacionais), 61.7% of energy production in 2020 came from renewable sources. Hydro and wind technology accounted for 28% and 24% respectively of this production. In addition, electricity production from fossil fuels decreased to 39.2% with a majority share of combined cycle and low utilisation of coal-fired power plants [4]. In fact, in January 2021, EDP closed the country's largest coal-fired power station in Sines. Currently, there is only one coal-fired power station still operating in Portugal, although it is scheduled to close in November 2021 [5]. There are no nuclear power plants in Portugal.

Demand coverage in 2020 accounted for an equal share of hydro and wind power (25%), while biomass energy (classic plants and cogeneration) contributed the highest share to date (7%). Solar photovoltaics contributed 2.6% to the coverage of electricity demand. From the point of view of fossil fuel power plants, gas-fired combined cycle plants supplied 34% of consumption, while coal-fired power plants achieved an all-time low of just 4% [4].

There are two fundamental issues that threaten the future of conventional technologies (coal, combined cycle and nuclear): the economic profitability of this type of power plants and the environmental damage caused by their operation.

From an economic point of view, the marginal market price is expected to decrease in the coming years as the share of renewables in the energy mix increases and demand decreases. Given that the income received by the different technologies corresponds to the amount of energy they generate each day and the daily price of electricity, it is possible that conventional plants do not recover all their investment costs through the daily market (for which there are in fact other mechanisms in many countries to remunerate the capacity they contribute to the system, in addition to the reserve markets, which also constitute another source of additional income). The fixed costs of these plants are high due to the amortization of the initial investment and the fixed part of the operation and maintenance costs. However, the variable costs are relatively low, so they are useful for producing for many hours. In addition, they are units that provide flexibility to the system, which is still necessary for the generation-demand balance [6] [7].

From an environmental point of view, coal power plants are the focus of the European Commission's plans to combat climate change due to the emission of polluting gases. It is estimated that coal will be phased out of the energy mix by 2025 [3]. Nuclear energy also has a complicated future despite the fact that it does not emit CO_2. The problem with these plants is the difficulty of managing their radioactive waste, which is harmful to the environment, the great impact that accidents can cause (even though they are very unlikely) and the pressure of public opinion against them. The main electricity Spanish companies (Endesa, Iberdrola, Naturgy) have already agreed to a staggered shutdown of their nuclear power plants between 2027 and 2035 [8].

At present, combined cycle plants play a fundamental role in ensuring the continuity and security of electricity supply thanks to their flexibility and high efficiency. In fact, in the draft of the "National Integrated Energy and Climate Plan 2021-2030” (PNIEC 2021-2030) the installed capacity of this technology remains practically constant [9]. This document establishes the basis for a strategic plan towards a future system of efficient, emission-free generation with a predominant volume of renewable energies. The issue is that by 2050 this type of technology may disappear according to European strategies and other types of technologies will be needed to compensate for the intermittency of renewables and ensure the generation-consumption balance.

This project proposes to analyse the profitability of the different generation technologies through a financial model based on the results of the CEVESA model for the simulation of the Iberian electricity market (MIBEL). For this purpose, a set of scenarios will be designed based on the current decarbonization plans included in the PNIEC of Spain and Portugal and the different evolutions will be studied, from the most optimistic to the most pessimistic possible. The financial module integrated in CEVESA will be designed to calculate the profitability of the generation technologies based on the long-term operation and investment results provided by CEVESA for each simulation scenario.

Both models will enable to assess the influence of renewables on the profitability of conventional technologies through the recovery or not of investment costs according to the different scenarios designed. This will assess the need to improve or not the viability of conventional generation plants that currently play a secondary role in the electricity system as backup power for renewables or as backup generation for the system, and the possible need for support mechanisms such as subsidies, incentives, or capacity mechanisms.

Objectives

The overall objective to be achieved with this final degree work is to analyse, through the development of appropriate tools, the future profitability of generation technologies in the face of different decarbonization scenarios based on the PNIEC 2021-2030 to assess the economic sustainability of the generation mix.

To achieve the aforementioned objective, a variety of tasks have been performed in response to the following specific targets:

1. Develop an analysis on the current role of generation technologies (combined cycle, wind, solar power, hydro…) in the electricity system considering the strategies of the European Commission and the regulatory policies promoted by the Spanish Government in relation to: taxes on polluting elements, renewable energy premiums and capacity payments.

2. Based on the possible results of the CEVESA model, define an economic model to calculate the profitability of the generation plants considering the cost and revenue factors in order to achieve the most reliable result possible.

3. Develop the model and integrate it into the CEVESA simulation environment.

4. Design a set of scenarios based on the PNIEC 2021-2030 targets, including their possible pessimistic and optimistic evolutions to achieve a fully decarbonized economy by 2050.

5. Applying CEVESA and the developed model, carry out the simulations corresponding to the scenarios designed to calculate the profitability of the generation technologies.

6. Analyse and compare the results obtained. Acquire the pertinent conclusions regarding the viability of the power generation plants.

Methodology

After the initial approach to the objectives of the work, an extensive literature review regarding the study of the cost-effectiveness of power generation technologies was conducted. Different economic methods have been evaluated to analyse the profitability of the different energy technologies, considering whether it is necessary to apply different models depending on the type of plant.

Once the profitability indicators that constitute the financial model were determined, the way to adjust it to the CEVESA market model was designed. This requires considering the potential costs and revenues of each technology. Part of the data will be provided by the CEVESA model, initially developed by the Technological Research Institute (IIT) of the Pontifical University of Comillas and in which the Institute of Systems and Computer Engineering, Technology and Science of the University of Porto (INESC TEC) is also currently collaborating ([10],[11], [12]). This model allows to estimate some output variables such as the price of electricity, the reserve price, CO2 emissions (in the case of coal-fired power plants and combined cycle gas turbines) and start-up and shutdown costs. The parameters not provided by the model will be obtained from bibliographic sources (price of emissions, annual demand level, taxes and premiums applied to each energy). In addition, the profitability of all technologies will be considered to depend on two common parameters: electricity price and annual demand. Variable costs (fuel and maintenance and operation costs), initial investment costs and production tax depend on the type of technology. Further, there are some costs associated only with specific types of plants such as CO2 emissions (coal and combined cycle plants), renewable energy premiums, capacity payments and the ENRESA fee paid by nuclear plants for future nuclear waste management and plant decommissioning [13].

Once the financial module has been adjusted to CEVESA's outputs, it is required to apply it to the different scenarios developed and based on the strategies established by the PNIEC. Depending on the outcome obtained, it was proceeded to determine which technologies would continue to be profitable in the coming years and which would not in alignment with the targets set by the government.

Chapter 1. THE PENINSULAR ELECTRICITY SYSTEM

This section briefly describes the historical evolution of the Spanish and Portuguese electricity sector from the 1970s to the present day, mentioning the technologies that currently constitute the generation park in both countries. Later, the functioning of the Iberian daily wholesale market is explained, highlighting the impact it has on the revenues received by each technology.

1.1. Evolution of the configuration of the Spanish electricity system

The generation technologies that constitute the electricity system in Spain have undergone a great evolution in recent years, thanks to the growing integration of renewable energies, the interest in reducing the participation of technologies that are more harmful to the environment and the need to ensure continuity of supply.

At the beginning of the 1970s, energy production in the national system depended almost exclusively and equally on hydroelectric power plants and thermal power plants (coal and fuel oil and gas). In previous years, most of the demand had been met by hydroelectric power, but the fall in oil prices favoured fuel oil production. Furthermore, in 1968, the first nuclear power plant was installed in Zorita de los Canes (Guadalajara).

In 1973, there was an excessive rise in oil prices that forced most of the countries dependent on this type of fuel to seek a solution to replace it with other cheaper sources. Spain opted for the development of nuclear energy to ensure energy independence and prevent further rises in the price of crude oil.

In the mid-1980s, major investments were made by the national electricity companies, resulting in the installation of 5,112 MW of power through thermal power plants, 4,695 MW nuclear and just over 3,000 MW hydroelectric [14]. At the end of the decade, the situation of the Spanish electricity sector was quite complex due to the existence of overcapacity and the financial unsustainability of the electricity companies after the high volume of investments made.

In 1997, the Spanish electricity sector was liberalised following the approval of Law 54/1997 and the electricity companies, until then in the control of the State, were privatised. This was a very important change that led to the creation of a wholesale electricity market whose operation and organisation would be managed by the electricity market operator (OMEL). Red Eléctrica de España (REE) was also created, responsible for the operation of the electricity system and the management of energy transmission and distribution [15].

Since the end of the 20th century, the government has been promoting the generation of energy from renewable sources, which until that time had been practically non-existent, with the exception of hydroelectric power. Through the Plan for the Promotion of Renewable Energies (2000-2010), the aim was to achieve the objective of generating 30% of electricity from renewable sources, mainly from wind farms. Renewable energies thus began their expansion, which continues to the present.

In the first years of the 21st century, electricity demand exceeded forecasts by more than 30%. Given that the reserve margin of the installed power plants was very reduced, the electricity sector was once again faced with serious problems in meeting any unforeseen variations in demand.

In 2002, the first combined cycle power plant was installed in Spain, marking the beginning of the massive construction of this type of technology. In just nine years, 67 gas cycles were built with a total installed capacity of 25,353 MW [16].

Another relevant event in the national electricity system occurred in 2006 with the creation of the Iberian Electricity Market (MIBEL), which was the union between the daily markets of Spain and Portugal. This unification improved efficiency and competition in the sector, providing greater security of supply. However, the economic crisis of 2008 again affected the evolution of the Spanish electricity system. System costs increased exponentially while demand decreased considerably.

In December 2015, the Paris Climate Conference (COP21) was celebrated where the first universal and legally binding agreement on climate change was agreed [17]. This document established the reduction of global carbon emissions as its main objective. Since then, the Spanish electricity sector has been evolving towards an emission-free and more efficient generation fleet.

By the end of 2020, installed electricity capacity in Spain exceeded 110,000 MW, 53.8% of which belonged to renewable technologies [1]. In particular, wind energy had 27,370 MW installed, surpassing combined cycle plants with 26,284 MW. Coal accounts for only

5,733 MW, the lowest figure to date following the closure of a large number of plants [18].

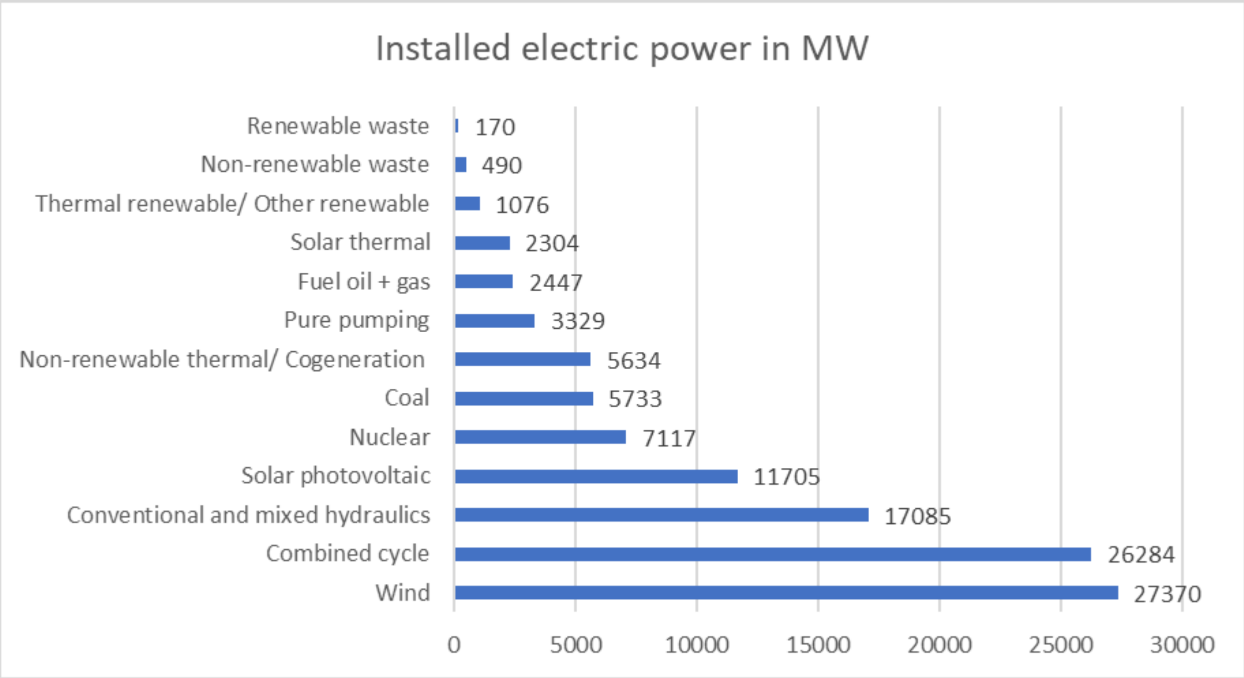


Figure 4: Installed electric power in MW in 2020 in Spain by energy source. Source: Statista, Own elaboration.

1.2. Evolution of the configuration of the Portuguese electricity system

At the beginning of the 1980s, the Portuguese electricity system consisted mainly of hydroelectric and conventional fuel oil thermal power plants, which accounted for 53% and 43% respectively of the country's electricity production. During that decade, due to the modernisation of the country and the increase in demand, the installation of coal-fired plants was promoted at the same time as the development of nuclear energy in Spain.

In 1997, the first natural gas generation plants were introduced, reaching 19% of the total production of the Portuguese system in 1999. The installed capacity of conventional thermal power plants (coal, fuel oil and gas) reached 5.06 GW in 1999 (47.2% of the total Portuguese generation fleet), exceeding the installed hydro capacity of 3.99 GW (37.2%) [19]. Portugal thus became one of the most energy-dependent countries in the world, having to import all the fuel used in the operation of fossil fuel power plants.

Since 2005, there has been a change in the structure of the Portuguese electricity system that has boosted the installation of renewable energies (especially wind energy) in order to reduce greenhouse gas emissions and dependence on external resources. To achieve this goal, the government promoted incentive policies with the aim of encouraging and supporting the expansion of wind and solar photovoltaic energy [20].

At the end of 2020, the installed renewable capacity of the Portuguese electricity system was 14,541 MW compared to 7,860 MW of fossil technologies. Within renewable energies, hydro represents the largest source of generation and installed capacity, followed by wind and solar photovoltaic energy. The latter has the greatest potential for growth in future years [21].

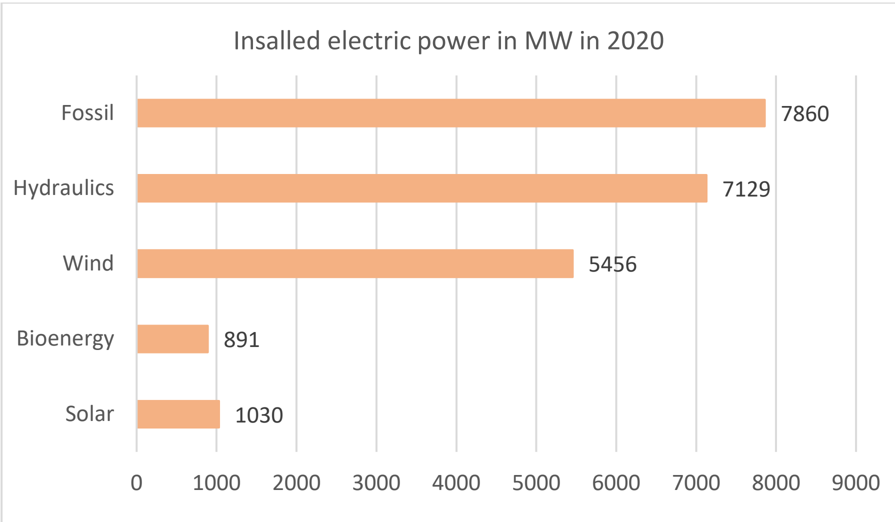


Figure 5: Installed electric power in MW in 2020 in Portugal by energy source. Source: DGEG, APREN. Own elaboration.

1.3. Iberian daily wholesale electricity market

Currently, the Spanish electricity market is integrated with the Portuguese market to constitute the MIBEL, which is composed of the daily market, the intraday auction markets, and the common intraday market. The organisation responsible for its management is the Operador del Mercado Ibérico de Energía-Polo Español (OMIE).

The MIBEL day-ahead market is linked to the other markets in north-central Europe, which provide greater security and continuity of electricity supply to the interconnected systems. They also facilitate the increased penetration of renewable energies [22].

In the Iberian daily market, the energy buying and selling agents of both countries establish their purchase and sale bids, respectively, for each hour of the following day. With this data OMIE constructs the hourly supply and demand curves.

The supply curve is constructed by aggregating the hourly bids by ascending price, including nuclear plants (low flexibility and high costs associated with power changes), flow hydro plants (low opportunity cost) and wind and solar renewable energies (unmanageable and with practically zero variable operating costs) in the lower part. In situations of high availability of renewable generation, their offers shift the supply curve to the right, causing a drop in the price of electricity. Therefore, they have a large impact on the market price. At the top of the supply curve are combined cycle and coal-fired power plants, and hydroelectric power plants with high opportunity costs.

The demand curve is constructed by aggregating the bids submitted for each hour by buyers in descending order of their price.

The point where the two curves intersect shows the market price for each hour of the next day. Since the Iberian market is a marginalist market, the market price sets the value that generators will exchange for the matched energy bids [23]. If saturation of the interconnection between Spain and Portugal occurs, the markets of each country are segregated and the market price for that hour will be different. However, if no saturation occurs, the markets are coupled, and the price will be the same for both countries.

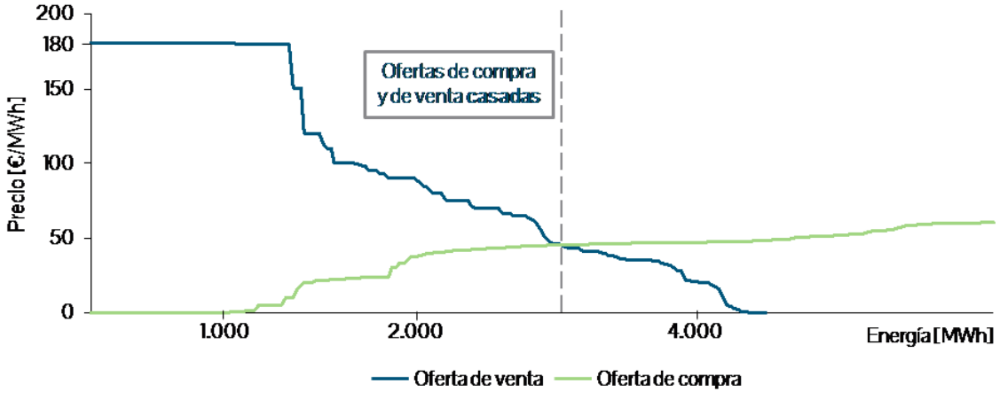


Figure 6: Daily market price determination. Source: OMIE.

The daily demand is first covered by the production of non-manageable renewable technologies and nuclear, leaving conventional thermal power plants such as combined cycle and coal as the last. The part of the demand that is covered by these technologies is called the thermal gap.

In recent years, the thermal gap has been reduced by the increase in the installation and production of renewable energies and the decrease in electricity demand following periods of economic crisis. This means less operation of combined cycle and conventional thermal technologies. Consequently, the number of hours that these technologies determined the marginal market price has also decreased. This reduction directly affects the revenues received by generation technologies.

Specifically, according to OMIE's annual report in 2020, combined cycle plants set the market price for 20.7% of the total hours in Spain and 20.6% in Portugal. In the case of coal-fired plants, the number of hours was much lower at 2.6% in Spain and 3% in Portugal. The technologies that set the market price on most occasions were hydro (45.8% and 47.4%) and the rest of renewables (wind, solar, cogeneration, waste and biomass among the most important) with 29.5% and 27.6% in Spain and Portugal, respectively [24].

Considering that the penetration of renewable energies will continue to increase in the coming years, this may pose a real problem for generation technologies in terms of recovering operating and investment costs.

Chapter 2. CURRENT SITUATION OF GENERATION TECHNOLOGIES IN THE SPANISH AND PORTUGUESE ELECTRICITY SYSTEM

This chapter describes the main characteristics of the most important generation technologies that configure the Spanish and Portuguese electricity system. It also explains the regulatory framework of each country under which these energy sources operate. Finally, it details the most efficient financial methods to determine the profitability of the different technologies based on the information gathered in already published studies.

2.1. General characteristics of generation technologies

2.1.1. Wind

It produces electricity by transforming the kinetic energy of the air currents generated by the wind. Its main advantages are the non-production of pollutant emissions, savings in fuel costs and the durability of its raw material. The main disadvantages of this technology are its discontinuous production and the difficulty of storing it. There are currently two types of wind farms: on-shore and off-shore.

The investment costs of wind farms (purchase of generation equipment and construction of the plant) are quite high in contrast to their almost zero variable costs (absence of fuel use and emissions).

2.1.2. Combined cycle

They generate electricity by converting thermal energy from natural gas into electricity using two adjacent thermodynamic cycles: one corresponding to a conventional gas turbine and the other to a steam turbine. It is the most advanced thermal technology with high efficiency and one of the lowest failure rates of all generation technologies. In addition, combined cycle power plants can adapt to electricity demand, making it an ideal technology for securing supply, acting as backup power in the presence of renewable sources. The two main drawbacks are fuel consumption and air pollution. Although they are less polluting than conventional thermal power plants, as CO2 emissions are low and SO_x and NO_x emissions are practically zero.

The initial investment costs of this type of technology are lower than the rest of the conventional thermal power plants and renewable energies. Variable costs depend mainly on the price of the fuel used (gas), the amount of CO_2 emissions emitted and the number of start-ups and shutdowns.

2.1.3. Hydraulics

It is the oldest renewable energy that allows electricity to be obtained by harnessing the energy of a moving body of water (located in the course of a river or retained in a reservoir) that drives an alternator coupled to a turbine. It is clean, inexhaustible and non-intermittent energy.

There are three types of hydroelectric power plants: flowing water plants (limited storage and production dependent on the amount of water received), reservoir plants (high-capacity water storage in a reservoir, high production flexibility and dependence on annual hydraulic contributions) and pumped-storage or reversible plants (they have two reservoirs at different levels of height and obtain energy by pumping water from the lower level to the upper level at times of low demand and vice versa at times of high demand and then passing it through a turbine to obtain electricity).

Their infrastructure and investment costs are high, especially in the case of reservoir and pumped-storage power plants. Their operating and maintenance costs are quite low as they do not require any type of fuel for their operation and do not emit any type of pollutant.

2.1.4. Solar

There are two ways of harnessing energy from the sun to convert it into electricity:

- **Solar photovoltaic**: converts solar radiation into electrical energy by using a photovoltaic cell made from conductive materials. There are two types of photovoltaic installations: solar panels for self-consumption and large power plants.

- **Solar thermoelectric**: thanks to the sun's energy, a fluid is heated, generating steam to drive a turbine and produce electricity.

Solar energy is a type of renewable energy and is therefore clean and inexhaustible. One of the disadvantages is the low efficiency of solar panels (around 15-20%) and the difficulty of storing the energy to produce electricity during periods when there is no light.

The initial investment costs are very high, although in recent years they have been drastically reduced. According to data published by the International Renewable Energy

Agency (Irena), the cost of energy of solar photovoltaic energy has decreased by 82% and the cost of solar thermal energy by 47% [25]. Operating costs are almost zero.

2.1.5. Nuclear

The electricity production process of this technology is based on the fission of the uranium nuclei used as fuel. The heat generated during the splitting of the atoms produces steam that drives a turbine and generates electricity. Nuclear power plants do not emit polluting gases into the atmosphere, although they generate nuclear waste that is difficult to degrade and harmful. They are efficient and inflexible, so they are not recommended for continuous operation.

The initial investment costs are very high, as are the fixed costs related to safety requirements, which have increased over time. In contrast, variable costs are relatively low.

2.1.6. Cogeneration

Cogeneration enables the simultaneous production of electrical energy and thermal energy. The main advantage of this technology is its high energy efficiency (around 80-90%) thanks to the use of less fuel by unifying the electricity and heat production processes into one. In addition, cogeneration plants are usually located close to the points of consumption, reducing energy losses through distribution.

2.1.7. Conventional thermal power plants (coal, natural gas and fuel oil)

This type of technology burns a fuel (coal, natural gas, or fuel oil) in a boiler generating heat used to produce steam at high pressures. The steam is used to power a turbine and produce electricity.

These plants emit pollutant gases and particles into the atmosphere, so in recent years they have been forced by governments to incorporate systems to reduce these emissions and to pay high taxes, negatively influencing their profitability.

The investment costs of this type of plant are high, as are the fuel costs. Fuel oil and natural gas plants are flexible, while coal-fired plants are significantly rigid.

2.2. Situation in Spain and regulatory framework.

Currently, the Spanish generation park is notable for its high installed renewable power capacity, making it one of the countries in the world with the greatest presence of clean technologies. The new objectives established in the new Climate Change Law and the Integrated National Energy and Climate Plan (2021-2030) (NECP), which reflect the country's medium-term energy planning and greater regulatory certainty, have favoured investment interest in renewable energies [26].

The Spanish energy mix will need to increase by around 60 GW of renewable energy by 2030 in order to meet the targets set. Most of this new installed capacity will correspond to wind and solar technologies. Given that these energies are intermittent in nature, it is essential to ensure energy supply to avoid production shortfalls. Spain has a level of interconnection with the rest of Europe that is far below the targets recommended by the European Union, so it is essential to guarantee back-up capacity for the system.

Two fundamental objectives for the energy transition are the decommissioning of coal-fired power plants, which have practically ceased to form part of the national energy mix, and the staggered closure of nuclear power plants from 2027, as planned by the government. Combined cycle plants, pumped hydro and batteries will therefore play a key role in covering electricity demand while the planned penetration of renewables set out in the NECP is achieved.

Gas-fired power plants in particular will be indispensable for this change, which is why it has been regulated to maintain the current installed capacity (26 GW) of this type of technology. At times of the year when other renewable energies are not able to cover demand, either because of a drastic increase in demand or due to meteorological phenomena (absence of sun and wind), the combined cycle plants, thanks to their flexibility, will have to support the system with their participation.

However, under the current design of the electricity market, which is based on remunerating only the energy produced, most of the current gas-fired plants present economic viability problems. In particular, considering the expected production values for the coming years of these technologies and OMIE's market price forecasts, the profitability of the plants does not augur a good future. In addition, CO2 prices are increasing due to stringent environmental commitments, making the problem even more difficult.

Therefore, there is a need to develop a capacity remuneration mechanism that allows combined cycle plants to cover their operating costs not only from revenues from the day-ahead market. This will ensure the stability of the electricity system [27].

Since 30 June 2018, combined cycle plants have not received any type of income in addition to the market price. On that date, they stopped receiving the capacity payments for availability according to Order ETU/1133/2017 of November 2017 which entailed an amount of €5,000 per year per installed MW. The main reason for the cancellation of this remuneration was due to Europe's proclamation of the forthcoming approval of a new model, the capacity mechanisms. In the end, this regulation was delayed, and gas-fired power plants have remained unremunerated to this day [28].

For this reason, the Ministry for Ecological Transition and the Demographic Challenge has prepared a draft Order creating a capacity market in the Spanish electricity system. It is constituted as a centralised system through which the system operator, Red Eléctrica de España, will contract the required firm power needs (in MW) detected in the demand coverage analyses for all time horizons [29].

The chosen system is a competitive auction mechanism similar to regulated auctions in the renewable sector and is of the type pay-as-bid. Therefore, each technology will bid for the price they are willing to charge for the availability of their firm capacity. Such quantity will be the price assigned to them in the case of an adjudication. The auctions will be called by resolution of the Secretary of State for Energy.

The regulation foresees two types of auctions: main auctions and adjustment auctions. The first will serve to guarantee the firm power needs for the peninsular electricity system. They are associated with a five-year capacity service provision period that starts within a maximum period of five years from the allocation of the service after the auction is held. The adjustment auctions will be used to solve hedging problems not covered by the firm capacity secured in the main auctions. They are associated with a twelve-month service provision period, starting no later than twelve months after the allocation of the service.

This new capacity market must comply with the general principles applicable to capacity mechanisms in accordance with Article 22 of Regulation (EU) 2019/943 of 5 June 2019 on the internal electricity market. Among these principles, the principle of technological neutrality is highlighted. It allows the participation in the capacity mechanism adopted by generation, storage, and demand as long as they comply with the established eligibility requirements. In addition, firmness ratios have been created, with the aim of setting equivalence between the different forms of generation provided by each technology in order to assess their availability capacity in times of energy scarcity [30].

Finally, a maximum CO2 emissions limit of 550 grams per kWh is also generally established for existing generation facilities participating in the mechanism, while new investments wishing to participate must prove that they are non-emitting installations.

As mentioned above, a similar remuneration mechanism applies to renewable production technologies. On 23 June, Royal Decree-Law 23/2020 was approved, establishing the obligation to develop by regulation a remuneration framework for electricity generation from renewable energy sources, different to the specific compensation system based on the long-term recognition of a price for energy.

On 4 December, Order TED/1161/2020 was approved, regulating the first auction mechanism for the granting of the economic regime for renewable energies and establishing the indicative calendar for the period 2020-2025.

The facilities participating in this system must produce electricity from renewable sources, cogeneration and waste and meet the following requirements: they must be new facilities or extensions to existing plants, be located in the peninsular electricity system and not have a storage system [31].

The main purpose of renewable auctions is to promote the penetration of renewables in Spain and to meet the proposed decarbonisation targets.

The first auction was held in January 2021 and resulted in a weighted average price of 24.47 euros per MWh for solar photovoltaic technology and 25.31 euros per MWh for wind power. In addition, 3,043 MW of green energy have been assigned.

Over the next few years, the government plans to allocate a minimum of 20 GW through renewable auctions until 2025, with photovoltaic being the predominant technology (minimum auctioned volume of 10 GW over the next six years) and closely followed by wind (8.5 GW). Solar thermal power, biomass and other technologies such as biogas, hydro and tidal power are also included (although with a smaller share) [32].

2.3. Situation in Portugal and regulatory framework.

Portugal, like Spain, has a high penetration of renewable energy sources.

In the coming years, Portugal's goal is to further increase the current installed capacity of renewable energy. However, the country has encountered difficulties in connecting more power plants. To find a cost-effective solution, the government has opted for renewable energy auctions, focusing mainly on solar energy. In these auctions, grid connection points are offered for connection to the grid where there is availability or where grid expansion is planned, in order to connect solar photovoltaic power plants. Successful tenderers must detail the volume of capacity they wish to purchase and choose the method of remuneration to the National Electricity System (NES).

This perspective allows the prioritisation of projects that generate a higher return for the NES and show guarantees of implementation. It also favours investors by providing greater predictability of revenues and a reduction in the risk of capital cost coverage.

One of the problems faced by Portugal, due to the size of its territory, are the surface area requirements for new wind and photovoltaic farms, which may hinder the installed capacity targets for these technologies.

2.4. State of the art on cost-effectiveness measures for different generation technologies.

The different characteristics of each technology in terms of both fixed and variable costs, as well as different subsidies or regulated tariffs, require an in-depth analysis and search for sources of information in order to determine the long-term profitability of each technology. The following are the most common and appropriate financial measures used in previous studies to analyse the revenues and costs of each technology.

Numerous projects have conducted various economic analyses to study the competitiveness of different generation technologies by calculating the levelized cost of electricity (LCOE). In [33], the LCOE is estimated using a mathematical model that considers both the shareholder's IRR and the IRR of the project analysed. This is a novel study since the LCOE had never been calculated through the shareholder's IRR, which allows including, in addition to traditional and general costs (initial costs, operation and maintenance costs, insurance, etc.), economic and financial factors such as depreciation, financial costs, taxes and bank financing. The economic model was tested in a solar thermal power plant in Extremadura (Spain). Subsequently, a financial sensitivity analysis was performed to assess which cost factors influence the LCOE result to a greater or lesser extent. This is useful for public policy considerations such as taxes and subsidies in order to minimise the LCOE and contribute to improving the profitability of the plant. The results of the project showed that the increase in net electricity production contributes to a decrease in LCOE, while investment costs, capital share and maintenance and operating costs cause an unfavourable increase in the viability of the solar plant. As detailed in the study [33], this economic method can be applied to other technologies to compare their cost-benefit values and facilitate investment decisions.

Another of the papers consulted [34], firstly, carries out a thermodynamic study in which it compares the energy benefits of using heat from the cooling of steam from a gas turbine in a combined cycle plant or directly from the cooling air. Secondly, it develops an economic analysis to determine the profitability of a combined cycle power plant, which is related to the objective of our project. The output data from the thermodynamic study have been used as input parameters for the economic analysis. The study uses the Net Present Value (NPV) which consists of the discounted net cash flow realised over the total duration of the investment, and the discount rate. The latter is calculated using the weighted average cost of capital (WACC). To calculate the net cash flow, the profits from the sale of electricity, the investment costs, the operating costs, the income tax, and the liquidation value are taken into account. The results of the paper show how the fuel price and the income tax rate have a decisive impact on the economic efficiency of the plant.

Another study of interest is [35] which compares the economic and financial performance of a nuclear reactor, a coal-fired power plant and a small-medium sized combined cycle gas turbine. The purpose of the research was to observe the effect of the carbon tax and the price of electricity on the economics of these power plants assuming different scenarios: with and without the application of the carbon tax. To do so, they calculate the LCOE and NPV and perform a Monte Carlo simulation. They assume that the price of electricity is constant and consider the costs associated with each technology, extra costs associated with CO2 production in the case of coal plants and combined cycle plants with respect to nuclear, obtained from different reliable sources. For each scenario they conclude that, in the absence of the carbon tax, the coal plant would be the most profitable due to its lower LCOE and higher NPV. However, when the CO2 tax is added, the results change and the nuclear plant becomes the most profitable technology, followed by the combined cycle plant, and lastly, the coal plant. Therefore, the study [35] concludes that the uncertainty regarding the carbon tax increases the investment risk for coal plants and to a lesser extent for combined cycle gas turbines.

In [36], an economic analysis (including both technical and financial factors) of a power plant whose input parameters (data such as temperature, pressure of steam conditions among others) are obtained through a thermodynamic model called Thermoflex (developed by Thermoflow) is performed. By changing these variables, 19,440 different simulations are run. The outputs of the model influence the costs, sales revenue, and fuel consumption of the plant. These results are used in the economic model to calculate the operating costs (OPEX) and revenues from electricity sales. Capital expenditure (CAPEX) and financial data for an operating Philippine power plant are also included. They then calculate the free cash flow by adding financial costs and taxes to the EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) generated by the operation of the plant. The value of the WACC is assumed to be known. Finally, an economic analysis is carried out by estimating the IRR and NPV to check the profitability of the plant.

Reference [37] describes another work similar to the previous one, although carried out on combined cycle gas turbines and based on the mathematical calculation of the NPV from the costs and revenues obtained from the CEVESA model which, as mentioned above, will be the reference model for this project.

The study [38] explains a set of economic measures used to assess the profitability of an investment: NPV, IRR, LCOE and Total-Life Cost of Capital (TLCC). Specifically, the aforementioned profitability indicators are defined and applied to power generation projects, considering initial investment costs, maintenance and operating costs, different rates imposed by governments and financial interest. The main advantage of these financial concepts is the possibility of estimating the long-term viability of projects based on factors such as investor perspective, regulation, financial and technical aspects. They also allow comparisons to be made between various technologies. These indicators are based on exogenous data from estimates of the expected production of the technologies and electricity prices. In addition, these data are obtained by means of engineering mathematical models that simulate the operation and expansion of electricity systems in the long term. These are known as expansion planning models and are divided into centralised decision models and equilibrium models. In [38], the mathematical equations that serve as a link between the financial measures and the mathematical models that represent centralised systems are detailed.

Finally, [39] specifies the relevant information for investors and developers of renewable energy projects to develop a financial analysis and business plan. This analysis is based on the calculation of the future cash flows of the project. To find these cash flows, the amount of money that will be received or paid in a project is considered and comes from three activities: operation, investment and financing. [39] defines operating activities as including revenues earned minus operating and maintenance costs and interest and revenue fees paid. Investing activity includes capital expenditures and cash flows from financing activity includes repayment of debt principal and dividends. Considering the above data, a set of economic methods are formulated to analyse the viability of the project: NPV, IRR, Capital Enrichment Ratio (CER), Payback Period and LCOE.

Regarding the previous studies, the objective of this project is to carry out a financial analysis of the power generation units of the peninsular electricity system to test and compare the profitability of these plants in the coming years. The financial model will be composed of the most common profitability indicators when valuing a project, such as NPV, IRR, LCOE, IP and TLCC. The results of the various parameters will give a broad picture of how easy it is for generation technologies to recover or not their investment costs. It will also show whether this situation may pose a threat to the security of supply and whether new investments are necessary.

Chapter 3. ECONOMIC VIABILITY OF GENERATION TECHNOLOGIES

This chapter will detail the operation of the mathematical model that simulates the Iberian electricity market and provides part of the data needed for the financial model. The revenues, costs and production of each generation unit are used as inputs to the profitability indicators used in this paper to analyse the viability of the different generation units that configure the Spanish and Portuguese electricity system.

3.1. Simulation model of the Iberian electric power system

The input data for the financial model have been obtained by applying CEVESA, a unit commitment model that simulates the operation and expansion of the electricity system of the Iberian market (MIBEL) in the long term. This model is currently shared by the Institute for Research in Technology of the Comillas Pontifical University (IIT) and the Institute for Systems and Computer Engineering, Technology and Science of the University of Oporto (INESC TEC).

3.1.1. Description of the model

The model is based on the balance between the operation and investment decisions of generators (GENCOS) in power plants and the investments made by customers in distributed energy resources (DER). The system is represented in a single node. GENCOS seek to maximise their total profits, while customers minimise their costs by considering tariffs and DER investments. Both aspects are linked through the hourly generation-demand balance and through the peak demand coverage constraint, which guarantees sufficient generation capacity for a certain level of security of supply.

Power plants (conventional thermal generation, renewable generation, and centralised storage) are represented per unit of supply until their expected year of closure and new investments are modelled by technology type (DC, open cycle gas turbine, wind, solar PV, storage). In particular, conventional thermal power plants are modelled on the basis of their maximum and minimum power, ramp-up and ramp-down, variable cost, fuel consumption, specific CO2 emissions and number of start-ups and shutdowns. The output of nuclear power plants is always set at maximum capacity. The hydro units are configured on the basis of weekly historical data on energy and reserve production, as well as their respective maximum and minimum values. Another CEVESA input data is the hourly production of non-dispatchable generation energies (wind and solar).

Customers are divided into 12 groups according to their sector of activity and sub-sector (food, paper, metallurgy, catering...) and buy and sell energy applying different tariffs for each type of transaction. Each customer group can invest in distributed generation (wind, solar PV, and storage). Each customer group can invest in distributed generation (wind, solar PV, and storage). CEVESA also considers energy distribution losses for each customer segment using a simplified approach.

In addition, CEVESA also replicates the transport sector by including investment decisions on internal combustion vehicles (ICEVs) and electric vehicles (EVs). For its representation, this model starts from an initial fleet of vehicles grouped into fleets. For each fleet, it considers O&M costs, investment costs, hourly usage profiles and energy consumption. Additionally, in the case of CEVs, it considers CO2 emissions and fuel costs. It also captures the diversity of charging strategies for PEVs: dummy, optimal charging, with or without provision of reserves (VSG/V2GR).

Recently, a new green energy source has been included in the model: hydrogen, as well as hydrogen powered vehicles (H2EV). The hydrogen production capacity is modelled by a single H2 plant considering its investment and variable costs as well as the estimated hourly hydrogen demand. Vehicle fleet, hourly usage profiles, energy consumption, fuel and infrastructure costs are necessary for the representation of H2EVs.

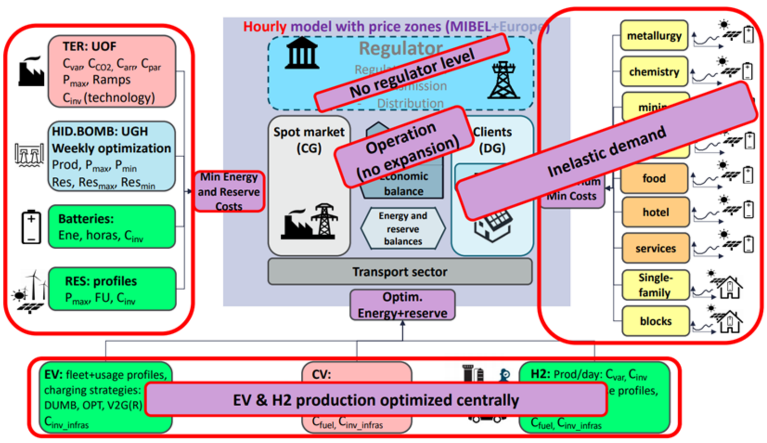


Figure 7: CEVESA simulation mode. Source: INESTEC.

Based on a predetermined level of demand and secondary reserve requirements, CEVESA provides hourly generation values for each unit of the Spanish electricity system, run on a weekly basis. In addition, it provides the short-term marginal cost of the system which is assumed to be equivalent to the wholesale price of electricity. The marginal cost of the secondary reserve band is also assumed to be equal to the market reserve price.

CEVESA can be used to simulate future scenarios based on a series of variable data such as annual demand, secondary reserve requirements, PEV and H2EV penetration, renewable energy penetration and CO2 price, among others. Some of the most relevant outputs of the model for each scenario are the hourly energy price, hourly reserve price, emissions costs, global costs, and the production levels of each technology.

3.1.2. CEVESA considerations in this study

Specifically, the model provides these data by unit (u) in the case of thermal power plants (revenues, start-up and shut-down costs, emissions costs, variable costs, and production) and hydroelectric plants (revenues, variable costs, and production). In reference to new investment technologies, data are provided by type of technology (wind, solar photovoltaic, solar thermal and cogeneration, among others). In the case of renewable energies, it provides revenues, O&M costs per MW and investment costs per MW, while for non-renewable energies, in addition to the aforementioned data, it provides the costs of emissions, variable costs and start-up and shut-down costs.

To facilitate the financial analysis, the new investment technologies were assumed as generation units (u) according to the type of technology with similar characteristics to the thermal supply and hydro management units. The financial model described below will allow the viability of these units to be analysed.

3.2. Financial model

To decide whether or not investing in an energy project is profitable, it is necessary to evaluate its economic viability by ensuring the recovery of initial investment costs. Therefore, this article will develop a financial model composed of several profitability indicators adapted to the different types of generation units. After an extensive literature review, it has been decided to apply the following financial indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index (PI) or Capital Enrichment Ratio (CER), Levelized Cost of Energy (LCOE) and the Total-Life Cost of Capital (TLCC).

Before proceeding to the calculation of the above parameters, it is necessary to obtain the annual cash flows for each technology. For this purpose, it was decided to apply a Discounted Cash Flow (DCF) model, commonly used to appraise companies, businesses, and projects. It is a financial valuation method used to estimate the present value of an investment based on its expected future Unlevered Free Cash Flows (UFCF), which are the cash flow available to pay all stakeholders (equity holders and debt holders). Therefore, is the amount of available cash a firm has after all operating expenses, capital expenditures, investments in working capital and before accounting for its financial obligations [40]. This method is commonly used to remove the impact of capital structure on a firm’s value and to make companies more comparable. It also proposes the calculation of the Net Present Value (NPV).

Three main types of cash flows are considered when calculating the UFCF: cash inflows, cash outflows and cost of capital (CAPEX).

Cash inflows

Represents income occurring in a specific period from operating activities. Depending on the type of generation unit, different sources of revenues were considered.

All system units involved in energy production receive income based on the established market price. In the case of supply units participating in secondary reserve regulation, the income received from this ancillary service was also considered.

As inputs to the financial model, they were computed for each year *t* as follows for each unit *u*:

$$REV_{t,u,z} = B_{u,z} \cdot \left[\sum_{h \in t} EP_h \cdot P_{h,u} + \sum_{h \in t} RP_h \cdot \left(UR_{h,u} + DR_{h,u} \right) \right]$$

Where $B_{u,z}$ is the Boolean parameter equals to 1 if unit u belongs to zone z, EP_h (1) represents the hourly selling price of electricity in the Iberian market; $P_{h,u}$ is the hourly production of each unit u; RP_h is the hourly reserve price in the Iberian market and finally $UR_{h,u}$ and $DR_{h,u}$ are the hourly reserve values to be raised and lowered of the plant u, respectively.

Cash outflows

These are expenses derived from the operation of the different technologies and typically include operation and maintenance (O&M) costs, fuel costs, personnel, insurance, etc. Fees paid to the government are also included in this section. Debt or financial costs are not considered as the capital structure of the company or project is ignored in the calculation of the UCFC. Depending on the type of generation units, the country in which they are operating, and the data provided by the CEVESA market model, certain costs or others must be included.

In the case of conventional thermal and hydraulic supply units currently operating in Spain and Portugal, variable costs have been considered for both, which depend on the plant's production. In addition, the thermal conventional plants, except the nuclear units from Spain, incurred in emissions costs and start-up and shut-down costs. The formula used for the calculation of the costs for the thermal (2) and hydraulic (3) units is shown below.

$$EXP_{t,u,z} = B_{u,z} \cdot \Bigg[EC_t \cdot \sum_{h \in t} Em_{h,u} + VC_{t,u} \cdot \sum_{h \in t} P_{h,u} + STC_{t,u} \cdot \sum_{h \in t} ST_{h,u} + SDC_{t,u} \cdot \sum_{h \in t} SD_{h,u}\Bigg], u \in ter \qquad (2)$$

$$EXP_{t,u,z} = B_{u,z} \cdot VC_{t,u} \cdot \sum_{h \in t} P_{h,u}, u \in hid \qquad (3)$$

Where EC_t is the CO_2 price in year t; $Em_{h,u}$ is the hourly emissions of the plant u; $VC_{t,u}$ is the annual variable cost of the plant u; $STC_{t,u}$ and $SDC_{t,u}$ the annual start-up and shut-down costs of the unit *u* respectively and finally, $ST_{h,u}$ and $SD_{h,u}$ representing the number of hourly start-ups and shut-downs of the plant u.

For new non-renewable investment units, the operation and maintenance (O&M) costs have been added to the costs mentioned above considering the country considering the country that is going to undertake such investments.

$$EXP_{t,u,z} = Com_{t,u,z} \cdot I_{t,u,z} + EC_{t,z} \cdot \sum_h EM_{t,u,z} + VC_{t,u,z} \cdot \sum_h P_{h,u,z} + STC_{t,u,z} \cdot \sum_h ST_{h,u,z} + SDC_{t,u,z} \cdot \sum_h SD_{h,u,z}, u \in nren \tag{4}$$

$Com_{t,u,z}$ are the operation and maintenance costs in year *t* of the technology u of the country *z*; and $I_{t,u,z} = B_{u,z} \cdot I_{t,u}$ is the total installed power.

In the case of renewable units, since they do not emit any pollutant emissions, do not consume any fuel as their operation depends on natural elements, only the O&M costs are considered.

$$EXP_{t,u,z} = Com_{t,u,z} \cdot I_{t,u,z}, u \in ren \tag{5}$$

This same formula applies to the wind and solar investment technologies:

$$EXP_{t,u,z} = Com_{t,u,z} \cdot I_{t,u,z} \tag{6}$$

<u>Taxes</u>

Depending on the country in which the generation units operate, they have to pay a number of fees for performing their activity and obtaining economic benefits. The following are the most important taxes that all energy production plants have to face.

Spain

<u>Tax on the Value of Electricity Production (IVPEE):</u> this is a direct tax of a real nature levied on the production activities and incorporation into the electricity system of electricity created in Title I of Law 15/2012 on 27 December. It applies to all electricity

production facilities under the ordinary and special regime (referred to in Title IV of Law 54/1997) regardless of the origin of the energy, size, or operating result. The tax rate is 7% and the tax period coincides with the calendar year [41].

Corporate income tax: This tax is payable by the electricity companies that own the generation plants, most of which are set up as public limited companies with their own legal personality that have been incorporated under Spanish law and have their registered office and effective place of management in Spain. The general tax rate for tax periods commencing on or after 1 January 2016 is 25%. However, entities engaged in the exploitation of hydrocarbons, such as combined cycle, coal, and oil power plants, among others, must pay a special tax rate of 30% (Law 34/1998) [42].

Portugal

Corporate income tax: The standard rate of corporate income tax for resident companies whose main activity is commercial, industrial or agricultural in nature, or for permanent establishments of non-resident companies carrying on such activities, is 21%, plus, in most municipalities, a municipal surcharge of 1.5%, which is levied on taxable income [43] .

In this paper, in the case of the Spanish units, a 7% IVPEE will be assumed, a 30% corporate tax for conventional thermal power plants and 25% for the rest of the units. Portuguese plants will face a corporate tax of 21%.

Cost of capital (CAPEX)

Capital expenditure is the investment in capital or fixed assets that a company makes to acquire, maintain, or improve its non-current assets, i.e., capital goods. Typically, in energy projects this refers to the initial purchase of plant and equipment that takes place at the start of the project. However, further investments may be made in the future to make any improvements to the plant. Investments may occur over a year or several years.

In this study, in order to analyse the viability of the combined cycle plants in operation in both countries, only the initial cost of the plant was taken into account, and it was assumed that this investment was made at the beginning of the plant's operation. Knowing the estimated years of useful life of each unit, the present value was calculated by deducting from the value of the initial investment the part that had already been depreciated, assuming a linear depreciation. This value was used as the initial capital expenditure in year 0 (2020) ($CI_{0,u,z}$). The data for each Spanish unit are shown in Annex I obtained from the source [44]. In the case of the Portuguese gas plants, as similar data were not available, investment costs similar to the Spanish plants with similar capacity were assumed, as shown in Annex II.

For new investment technologies CEVESA will provide the annual investment costs of each technology per MW ($CIv_{t,u,z}$) and the annual investment results, meaning the power installed each year during the period analysed ($I_{t,u,z}$). Since the analysis will assume 2020 as the starting year of the investment, the investment cost of that year will be considered as the initial investment figure ($CI_{0,u,z}$). Taking this into consideration, the investment costs incurred in the period analysed were calculated for each technology *u* in each country *z*.

$$CI_{t,u,z} = CIv_{t,u,z} \cdot I_{t,u,z} \tag{7}$$

where $CIv_{t,u,z}$ is the variable cost of the investments and $CI_{t,u,z}$ is the investment cost [€].

As CEVESA also provides the estimated lifetime values for each type of technology *u* and country *z*, the linear amortisation $Amort_{u,t,z}$ of the initial cost ($CI_{0,u,z}$) of the new investment technologies was calculated.

3.2.1. Net Present Value

The NPV is the value of all future cash flows over the entire life of an investment discounted to the present, considering the relevant discount rate for the company according to its debt structure and the profitability demanded by the shareholders. The main advantage of this financial measure is that it accounts for the value of growth opportunities, the time value of money and the cost of capital.

The NPV equation for each generation unit *u* is shown below (from now on the formulae do not explicitly show indexes *u* and *z*, for simplicity):

$$NPV = \sum_{t=1}^{T} \frac{FCF_t}{(1+r)^t} - CI_0 \tag{8}$$

Where FCF_t is the net cash flow at period t explained later, CI_0 is the total initial investment at period 0 (CAPEX); t is the time of the cash flow (annual); T the total number of periods and r is the discount rate.

A project or company shall be considered profitable if its net present value is positive and therefore creates value. If the net present value, is negative it means the expected rate of return that will be earned on it is less than the discount rate. However, it does not always mean that the project is unprofitable and does not generate accounting profits (net income), but rather that as the rate of return generated is lower than the discount rate, it is considered value destroying.

The Net Cash Flow is calculated starting from the Net Income (NI_t) by adding the annual amortisation ($Amort_t$) and subtracting the investment cost during the period (CI_t) excluding the initial investment (in year 0):

$$FCF_t = NI_t + Amort_t - CI_t \tag{9}$$

Net Income consists of Earnings Before Taxes (EBT_t) minus the value of corporate income tax ($CTax$).

$$NI_t = EBT_t \cdot (1 - CTax) \tag{10}$$

The EBT equation is shown below where interest, depreciation and amortisation are deducted from earnings before interest, taxes, depreciation, and amortisation (EBITDA). In this study the interest paid by the company to finance the project will not be considered and the accounting treatment of the initial investment cost (amortisation) will be assessed.

Amortisation shall be taken into account for existing combined cycle plants and new investments in renewables. Hydro units shall be considered as already amortised.

$$EBT_t = EBITDA_t - Amort_t \tag{11}$$

Finally, EBITDA is computed by deducting from the revenues corresponding to each type of technology shown in equation (1), the operating expenses (EXP) shown in equations (2), (3), (4) and (5). Here is also deducted the tax on electricity production (IVPEE) applied to the revenues of the Spanish power plants.

$$EBITDA_t = REV_t \cdot (1 - IVPEE) - EXP_t \tag{12}$$

WACC

In this study, considering that the annual output data of the CEVESA model are real values which means they do not incorporate the inflation of each year with respect to the initial year of execution, a real discount rate will be used. Specifically, the Weighted Average Cost of Capital (WACC) will be used, which is widely used to value companies or investment projects using the discounted expected cash flow method. This parameter considers both the company's own and external sources of resources. A remuneration of investments with a return equal to the WACC implies that the company will be able to obtain the necessary funds from the market to carry out the planned investments, thus ensuring its continuity and expansion [45]. The main advantage of the WACC is that it determines the cost of the investment independently of the sources of financing in order to determine a rate of return that is higher than the WACC and therefore generates added value for shareholders. It should also be noted that the WACC assumes that the capital structure remains constant, so it does not consider the possibility of the company reducing or increasing its level of indebtedness in the future [46]. Its calculation is not very complex, but it will not be the subject of this work, so it will be assumed as exogenous data. Based on the values of the discount rate used in the studies mentioned in the point above (*2.4. State of the art on cost-effectiveness measures for different generation technologies),* it has been decided to opt for a value of 6%. Although in reality the values differ by technology, the same WACC will be assumed for the different units in order to facilitate further comparison.

3.2.2 Internal Rate of Return

The internal rate of return (IRR) is the rate of interest or profitability offered by an investment. In other words, it reflects the profitability of a project or company through the discounted benefits and payments that the investment will generate. It is expressed as a percentage and is also known as the discount rate that makes the NPV of a given investment project 0.

$$NPV = NPV(r)$$
$$NPV(r = IRR) = 0 \tag{13}$$

When assessing whether a project or company is profitable or not based on the IRR, it is necessary to compare it with the discount rate used to find the NPV. In this study, it was compared with the WACC. As long as the IRR is higher than the WACC, the project is considered viable if it exceeds the minimum required profitability. If the IRR is equal to or less than the WACC, the chances of making a profit on the investment are very low and projects are usually rejected.

This profitability indicator is, together with NPV, one of the most widely used by investors when making decisions, although it has some drawbacks. One of them is that the IRR is not able to differentiate investment sizes, so it is only useful for comparing projects with very similar investment scales. In addition, a higher IRR value does not necessarily lead to a higher NPV for the investor.

3.2.3 Levelized Cost of Energy (LCOE)

The LCOE is a very interesting profitability indicator for evaluating energy projects, especially renewable energy projects. It is the value of the total current cost of constructing and operating an energy generating facility over its lifetime. It is therefore calculated by dividing the present value of the cost flows that the plant will have over its lifetime by the present value of the total energy production during all the years of operation. A discount rate is used for this purpose, which in this paper is equivalent to the WACC. If there is an initial capital investment it has to be considered and added to the present value of the operating costs.

In this work, it was calculated for all units, both for new and existing investments. The formula used is shown below and takes into account the corporate tax expense:

$$LCOE = \frac{IC_0 + \sum_{t=1}^{T} \frac{TOTC_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{P_t}{(1+r)^t}} = \frac{IC_0 + \sum_{t=1}^{T} \frac{CI_t + EXP_t \cdot (1-CTax) - Amortz_t \cdot CTax}{(1+r)^t}}{\sum_{t=1}^{T} \frac{P_t \cdot (1-CTax)}{(1+r)^t}} \tag{14}$$

IC_0 is the total initial investment at period 0 (CAPEX); $TOTC_t$ are the total costs in year t arising from the operation of the generation technology (equations (2), (3), (4) and (5) as a function of the type of energy) and amortisation costs; P_t is the production of energy in year t.

The LCOE is very useful as it allows a direct comparison of the costs of different energy sources. The lower the LCOE value, the higher the profitability for the investor. However, this measure of economic viability also has some drawbacks as it can give misleading results when comparing technologies that produce electricity in periods with different prices.

3.2.4. Profitability Index (PI) or Capital Enrichment Ratio (CER)

This investment appraisal method measures the present value of the net cash flows for each monetary unit invested in the project. It is calculated by dividing the present value of the net cash flows by the initial investment or the present value of the investment flows occurring in the period under analysis.

$$PI = \frac{\frac{\sum_{t=1}^{T} FCF_t}{(1+r)^t}}{(IC_0 + \frac{\sum_{t=1}^{T} CI_t}{(1+r)^t})} \tag{15}$$

CI_t are the investments cash flows at period t.

If PI is greater than 1, the project is profitable as the present value of the benefits is greater than the initial investment or the investment costs. If, on the other hand, PI is less than 1, it is not advisable to invest in the project as the investment costs will not be recovered. The further the value of PI moves away from (below) unity, the more (less) attractive a project becomes.

3.2.5. Total Life Cost of Capital (TLCC)

The TLCC of a project is the sum of all costs discounted over its lifetime, i.e., from purchase to disposal. The costs include cash outflows related to investments, construction, operation and maintenance costs, financial costs, amortisation, and capital subsidies, among others. The formula applied in the financial model developed in this study is shown below and includes the corporate tax expense:

$$TLCC = \frac{IC_0}{1 - CTax} + \sum_{t=1}^{T} \frac{CI_t + EXP_t \cdot (1 - CTax) - CTax \cdot Amort_t}{(1 - CTax) \cdot (1 + r)^t} \quad (16)$$

If the revenues generated by the plant or technology in question over its lifetime are greater than the TLCC, it is profitable. If, on the other hand, the TLCC is higher than the revenues, the costs of operating the plant prevent the economic viability of the project.

Both the net cash flows, and the other indicators were calculated for each unit of supply through Excel using the Power Query add-in. This tool was used because of its efficiency in updating the results according to the values assigned to the input parameters. The following chapter specifies the scenarios to which the financial model was applied, and the results obtained.

Chapter 4. SCENARIO ANALYSIS

This chapter presents the scenarios based on the NECPs of Spain and Portugal that are the target of analysis of this work. This is how the CEVESA market model, and the financial model explained in the previous chapter will be applied to each scenario allowing to obtain results that determine the viability of the generation technologies in the future.

4.1. Design of the scenarios

The regulation of energy and climate policy in Spain and Portugal is determined by the European Union, which in turn is committed to the requirements adopted in the Paris Agreement. The main objective of this universal accord is to avoid dangerous climate change by keeping global warming below 2ºC and to try to limit it to 1.5ºC. Global emissions reductions were also agreed.

In 2016, the European Commission presented the Legislative Package "Clean Energy for All Europeans" with the aim of promoting the energy transition in the decade 2021-2030. This package requires each country to elaborate and submit an Integrated National Energy and Climate Plan (NECP) for the 2030 horizon on renewable energy, energy efficiency, energy security, innovation, greenhouse gases and a vision for achieving them.

In this context, the European Union approved a series of objectives that it intends to achieve by 2030: 32% of the share of energy should come from renewable sources, a 32.5% reduction in energy consumption, a 40% decrease in greenhouse gas (GHG) emissions compared to 1990 levels and the increase of electricity interconnections between Member States by 15%.

In November 2018, the European Commission updated its long-term strategic vision through the "Clean Planet for All" package with the aim for the European Union to achieve a prosperous, modern, competitive, and climate-neutral economy by 2050.

Spain has already developed its own NECP reflecting its commitment to the EU's 2021-2030 targets. The document specifies the process, objectives, policies, and measures in place as well as those necessary to achieve the Plan's ambitions. It also details the analysis of the economic impact and health benefits associated with the implementation of the plan [47].

The Spanish energy system produces three out of every four tonnes of greenhouse gases, so the energy transition will focus on decarbonisation.

The application of the measures included in the NECP will make it possible to achieve a 23% reduction in greenhouse gas emissions compared to 1990 by the year 2030, according to a study conducted by the government. In addition, a 39.5% improvement in energy efficiency will be achieved and 74% of electricity generation will come from renewable sources.

Portugal has also drafted and approved its respective NECP with the aim of achieving carbon neutrality by 2050 and in line with the EU target. To this end, it envisages an increase in renewable energy capacity of up to 28.8 GW, which will involve an investment of close to 18 billion euros.

The targets proposed in the document are a 35% improvement in energy efficiency, a 45-55% reduction in GHG emissions compared to 2005 figures, a 47% increase in renewable energy sources and a 15% improvement in electricity interconnections [48].

In order to analyse the economic profitability of the new investments (solar photovoltaic and wind) planned in the NECP of both countries and the main support technologies, which in this case are the existing gas combined cycle plants, two possible scenarios have been designed. These scenarios are detailed in [49] and reflect a base scenario configured on the basis of the values proposed in the NECP for different parameters, as well as a scenario representing a pessimistic evolution with respect to the base case.

The solar and wind generation profiles are based on 2015 data but considering 2019 capacity factors and scaled to the installed capacity corresponding to each scenario. The solar thermal generation profile and demand profile are based on 2019 data, scaled for the remaining years depending on the scenario. Finally, data on installed capacity for technologies such as cogeneration, biomass, renewable and non-renewable waste were considered constant with 2019 values.

The data collected in the NECPs correspond to the period 2021-2030 but in order to obtain a more reliable financial analysis, it has been chosen to extend the analysis interval to 2050. Therefore, each input parameter of the CEVESA market model has values until

2050. To achieve greater accuracy in the economic analysis it would have been desirable to run the CEVESA model on an annual basis, however, due to time constraints, it has been decided to reduce the simulation to a set of reduce years, with intermediate outputs been estimated by linear interpolation with the simulated years outputs.

4.1.1. NECP scenario

This scenario has been developed on the basis of the targets proposed by the Spanish and Portuguese governments for new installed capacity over the next decade (2021-2030) and reference [49] where different scenarios are build based on the NECPs. The data for the years after 2030 are estimated, so that the installed capacity of wind and solar photovoltaic energy in 2050 in Spain is expected to be 64.33 GW and 53.181 GW, respectively. In Portugal, 23.3 GW of wind power and 23 GW of solar PV plants are expected to be installed.

Considering the commitment of the countries to reduce CO2 emissions, the NECP includes the need to shut down most of the thermal generation units, with the exception of combined cycle plants. Below is an outline of the planned closure dates for the remaining coal-fired plants and the nuclear units that currently make up the Iberian fleet [49].

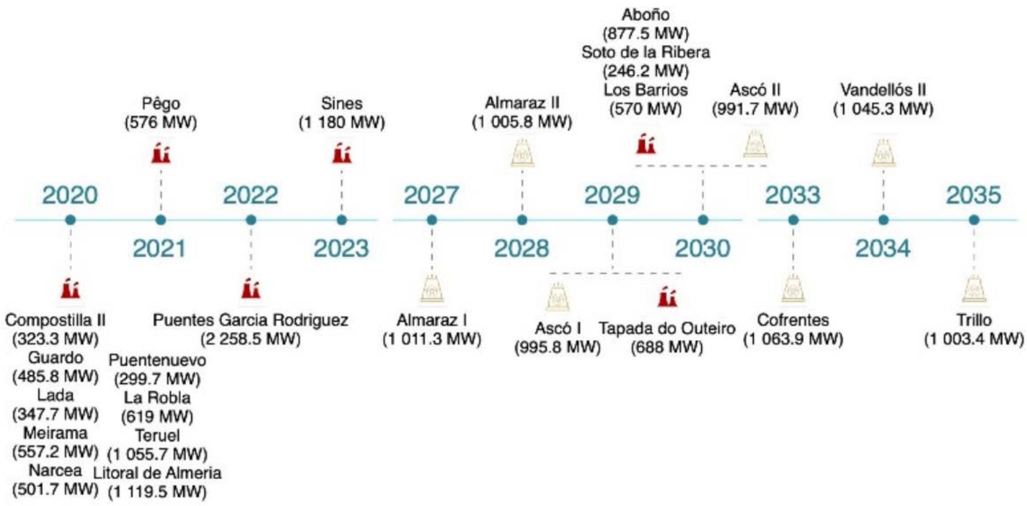


Figure 8: Predicted decommissions of thermal units.

For this reason, this scenario forecasts a progressive increase in CO2 prices that will affect those plants that remain active (mostly combined cycle plants). Prices of 15, 22.5, 33.5 €/tonne for 2020, 2025 and 2030 respectively are taken from [49]. The value for the following years was extrapolated and correspond to 48 €/ton.

A worldwide increase in demand is also foreseen in the coming years. Electricity consumption in developing countries is increasing, as is the use of electricity in industrial processes, transport, and household appliances. In addition, forecasts of improved energy efficiency and economic growth contribute to higher consumption. Specifically in the Iberian Peninsula countries, between 2020 and 2025 a year-on-year growth of 0.6% is expected and between 2025 and 2050 a year-on-year growth of 1.9%.

Fuel prices are assumed constant throughout the analysis period (until 2050) and are based on March 2020 data: 9 €/MWh for TTF and 47 €/ton for API2.

Finally, a generalised rise in interconnection capacity between EU member countries is expected in view of the forecast increases in demand. Therefore, the interconnection capacity between Spain and Portugal will grow from 2000 GW in 2020 to 3600 GW in 2025, continuing with an increase to 4200 GW in 2030. From 2040, the interconnection will reach 4700 GW.

The above-mentioned parameters are summarised in two tables, one for each country, and will be used as input data in the CEVESA model. The base year refers to the initial year of the analysis, which in this case is 2020. The values for the year 2050 have been obtained by extrapolating the figures of previous years that include the measures proposed in the INECP.

Parameters	**Estimated values**		
	Base	**Increment**	**2050**
Wind capacity (GW)	28.033	140.2 %	67.333
Solar capacity (GW)	9.071	519.35 %	56.181
Battery capacity (GW)	0	100 %	19.5
Total expected demand (GWh)	250638.86	64.95 %	413421.37
Interconnection capacity (ESP-POR) (MW)	2000	135 %	4700
CO_2 prices (€/ton)	15	220 %	48
API2 prices (€/ton)	47	0 %	47
TTF prices (€/MWh)	9	0 %	9

Table I. Parameters for the Spanish NECP scenario in 2050.

Parameters	Estimated values		
	Base	Increment	2050
Wind capacity (GW)	5,4	331.5 %	23.3
Solar capacity (GW)	2	519.35 %	23
Battery capacity (GW)	0	-	0
Total expected demand (GWh)	50648.076	64.95%	83542.5
Interconnection capacity (POR-ESP) (MW)	2000	100 %	4000
CO_2 prices (€/ton)	15	220 %	48
API2 prices (€/ton)	47	0 %	47
TTF prices (€/MWh)	9	0 %	9

Table II. Parameters for the Portuguese NECP scenario in 2050.

4.1.2. Pessimistic scenario

This scenario envisages a less favourable evolution in terms of meeting the targets proposed in the NECPs. Due to the difficulty of predicting electricity demand in the coming years and external factors that may influence compliance with the proposed targets, this scenario will consider a decrease in installed capacity of 15 % with respect to the base values (Table I and Table II). Therefore, in 2050, 54.683 GW of wind energy and 45.204 GW of solar photovoltaic energy will be installed in Spain. In Portugal, these figures will correspond to 19.805 GW of wind farms and 19.55 GW of solar panels [49].

Interannual demand growth is assumed to be 0.8% between 2020 and 2025 and 2.5% between 2025 and 2050 in Spain and Portugal. Considering a pessimistic scenario, it is reasonable to assume a higher demand increase than initially expected. The forecast demand for 2050 in Spain is 484518.38 GWh and in Portugal 97909.49 GWh.

The closure date of the nuclear power plants in Spain and the coal-fired plants still operating on the Peninsula would be delayed by two years compared to the dates foreseen in Figure 8. This event will lead to higher CO2 emissions and more difficulties in achieving climate neutrality in 2050. CO2 prices will be more expensive than in the NECPs scenario. The carbon price will be 15, 32.5 and 43.5 €/ton in 2020, 2025 and 2030, respectively. From 2035 onwards the price will rise to 58 €/ton and remain at this level until 2050.

The fuel price also rises, reaching 19 €/MWh for TTF and 57 €/ton for API2. Rising carbon and fuel prices will lead to higher operating costs for coal-fired and combined cycle power plants.

Finally, interconnection capacity between Spain and Portugal is expected to decrease by 25% compared to the baseline scenario. That is, in 2020 it will be 1500 GW and will increase to 2700 GW in 2025. In 2030 the interconnection capacity will be 3150 GW and will finally reach 3525 GW in 2040.

The contemplation of a greater increase in electricity demand combined with a lower number of investments in renewables could pose serious problems for meeting the European Union's objectives of a 100% emission-free generation mix by 2050, as it will depend on conventional power plants to ensure the continuity of energy supply.

Parameters	**Estimated values**		
	Base (2020)	**Increment**	**2050**
Wind capacity (GW)	23.828	137.9 %	54.683
Solar capacity (GW)	7.710	486.3 %	45.204
Battery capacity (GW)	0	100 %	14.025
Total expected demand (GWh)	251137.152	92.93 %	484518.384
Interconnection capacity (ESP-POR) (MW)	1500	135 %	3525
CO_2 prices (€/ton)	15	286 %	58
API2 prices (€/ton)	57	0 %	57
TTF prices (€/MWh)	19	0 %	19

Table III. Parameters for the Spanish PESS scenario in 2050.

Parameters	**Estimated values**		
	Base (2020)	**Increment**	**2050**
Wind capacity (GW)	4.59	331.5 %	19.805
Solar capacity (GW)	1.7	1050 %	19.55
Battery capacity (GW)	0	-	0
Total expected demand (GWh)	50748.768	92.93%	97909.492
Interconnection capacity (POR-ESP) (MW)	1950	53.84 %	3000
CO_2 prices (€/ton)	15	286 %	58
API2 prices (€/ton)	57	0 %	57
TTF prices (€/MWh)	19	0 %	19

Table IV. Parameters for the Portuguese PESS scenario in 2050.

4.2. Scenario results

Depending on the input parameters of CEVESA model that define each scenario, different results have been obtained. The analysis of the results has focused on new investments in wind and solar photovoltaic energy and on the existing combined cycle plants that will have to operate to ensure electricity supply.

In this study, the CEVESA model is run by first solving an investment problem followed by an operational problem. Through the investment execution mode, the new power to be installed is determined according to the input parameters and the established restrictions. Through the operating model, the revenues, costs, and productions of the generation technologies represented in CEVESA are obtained.

When carrying out the simulation in CEVESA to solve the investment problem in both scenarios, a restriction on CO2 emissions stipulated by the European Union was included, whose reference appears in the following document [12]. This constraint forces investments in renewables to be high in order to reduce thermal generation. Therefore, the results of new investments in addition to cost minimisation and demand coverage take into consideration the emission limitations.

Considering that the emissions constraint has no safety coefficient, it is very likely that, in operation mode, the generation technologies are producing at the limit of their capacity. This situation causes that in certain hours the model provides a marginal cost (assumed equal to the market price) between the present value and the cost of the energy not supplied. Currently, in the model, the price of energy not supplied corresponds to 1000 €/MWh. In the real market, the cost is limited to 3000 €/MWh although until recently the limit price was 180 €/MWh, so the amount considered in CEVESA is reasonable.

The results obtained in the two scenarios reflect episodes of high prices from 2035 onwards, which will be close to the price of energy not supplied.

4.2.1. NECP scenario

Investments in new renewable technologies, mainly wind and solar energy, to meet the targets for clean generation in 2030 proposed in the NECPs have already been considered in the corresponding plans. For this reason, the cumulative installed capacity of wind and solar energy in Spain (Figure 9) remains constant from 2020 to 2030 since no additional capacity is needed. The annual production in MW of these technologies during these years remains constant as shown in Figure 10. Coverage of demand during this first decade is reinforced by the existing combined cycle plants, as their production increases progressively as demand grows.

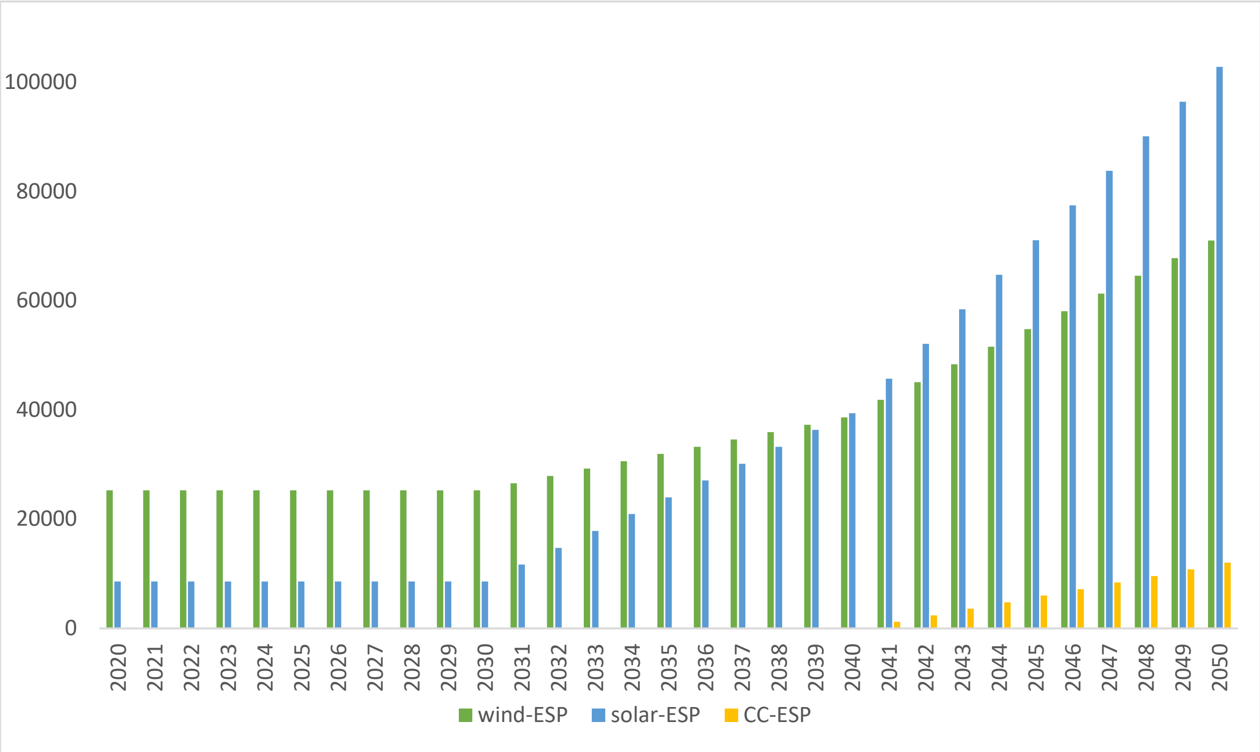


Figure 9: Evolution of accumulated installed power in Spain under the NECP scenario (MW).

In addition, between 2027 and 2035, 7.117 GW of nuclear power and 1.694 GW of coal-fired plants are expected to be disconnected from the Spanish generating fleet. Combined cycle plants act as a back-up technology, reaching peak production in 2030. To compensate for the reduction in installed capacity and achieve the emission-free electricity generation targets in 2050, new investments in renewable technologies are needed. From 2031 onwards, the installed capacity of wind and solar power starts to grow progressively, reaching 71.027 GW and 102.79 GW respectively by 2050. The large amount of installed capacity of photovoltaic plants is remarkable compared to the path set by the NECP (56.181 GW). One of the reasons for this is the European Union's emission limits, which are becoming more restrictive as 2050 approaches. The difference in installed capacity between wind and solar energy may be due to the limited capacity factor of solar energy (currently between 10% and 30%). In addition, the investment costs of photovoltaic panels have been reduced considerably in recent years, improving their future prospects.

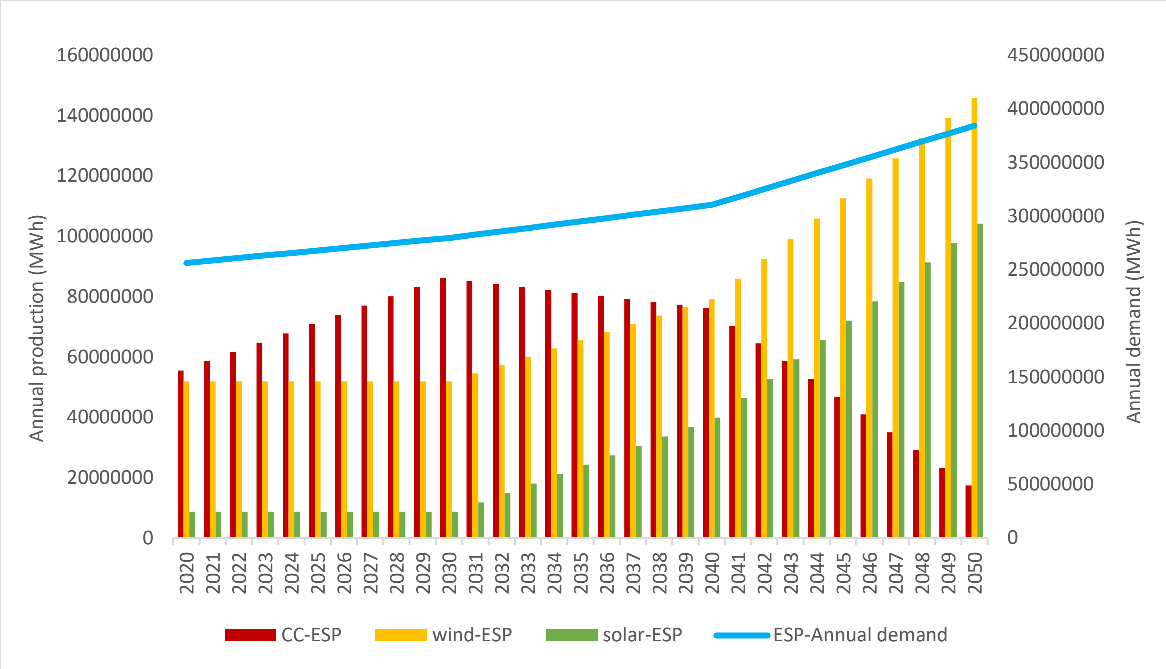


Figure 10: Annual production technologies and annual demand in Spain under the NECP scenario (MWh).

A similar situation occurs in Portugal, although new investments in renewables do not take place until 2041. As in Spain, wind and solar power generation remains constant until new capacity is installed. Bearing in mind that demand in Portugal will also increase significantly in the coming years and that the last thermal power plant is scheduled to close in 2029, the increase in gas-fired generation is understandable. Also because the CO_2 restriction is only activated for Spain, which leaves Portugal to invest in the cycles in which Spain cannot. In fact, figure 12 shows that in 2030 there will be an increasing change in the slope of the demand curve. Given the lack of new renewable installed capacity until 2040, the incorporation of new MW of combined cycle plants to the Portuguese park is shown in figure 11.

From 2040 onwards, electricity demand increases considerably, and new investments in renewable generation gradually replace combined cycle plants in terms of production.

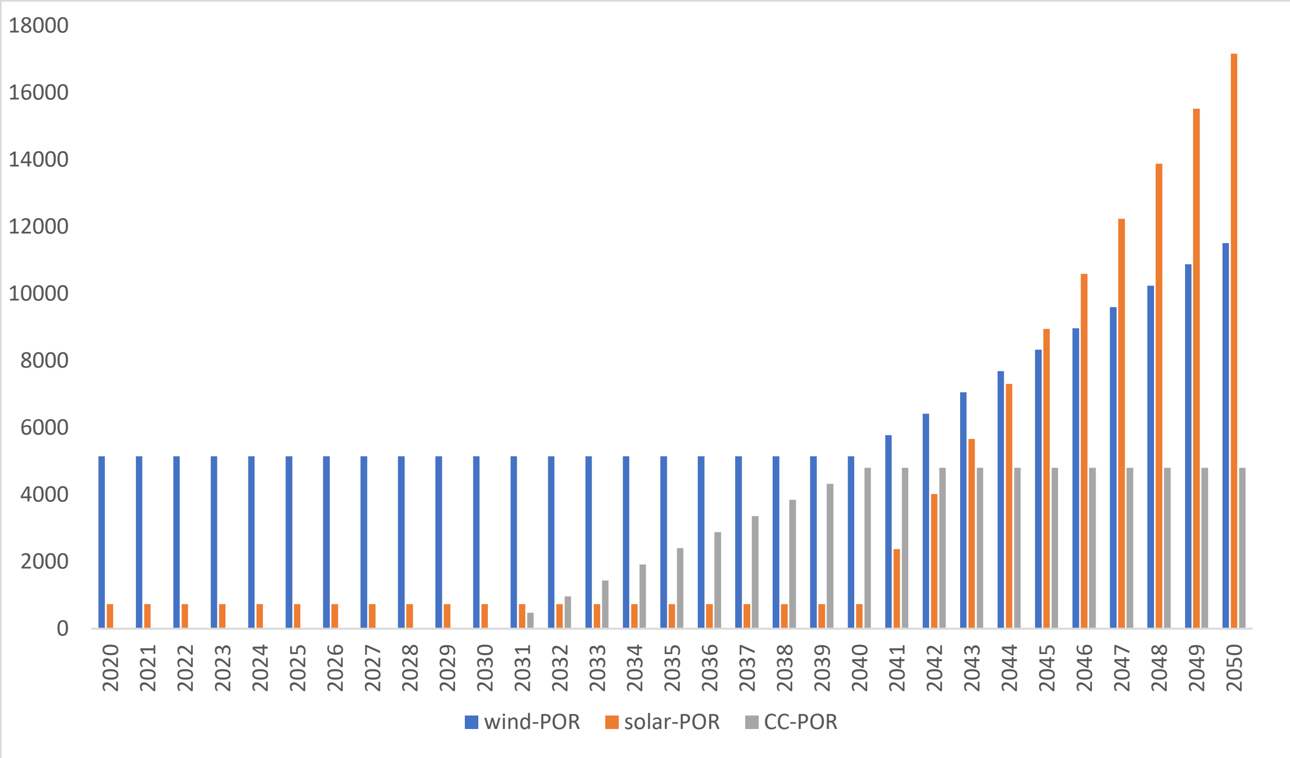


Figure 11: Evolution of accumulated installed power in Portugal under the NECP scenario (MW).

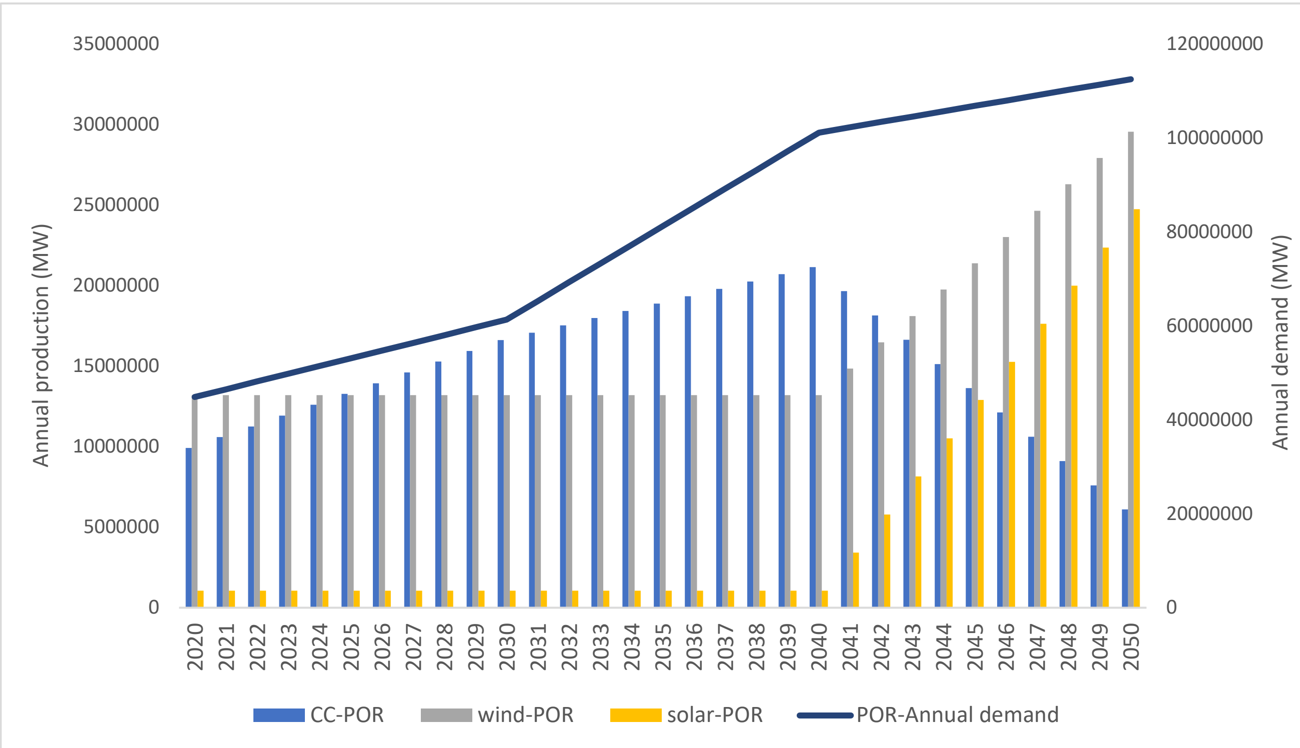


Figure 12: Annual production technologies and annual demand in Portugal under the NECP scenario (MWh).

Figures 13 and 14 show the results of the annual net cash flows of the wind and solar investments as well as the combined cycle investments in each country. To calculate the net cash flow of the combined cycles, the results obtained in the financial model of all the supply units have been grouped together. In both Spain and Portugal, the situation is similar when configuring the same market. Until 2030, cash flows are negative for all three types of technologies. This situation is understandable given that the initial investments represent a high cost that takes years to recover. Furthermore, market prices during the first years of analysis obtained from the CEVESA model are between 20 and 35 €/MWh and are the same in both countries. However, around 2035, year when demand starts to grow more sharply, there are hours of generation shortages resulting in high market prices close to the cost of energy not supplied. The market price in Spain in 2040 and 2050 is 695.252 €/MWh and 594.178 €/MWh, respectively. Due to the lack of power, the interconnection between Spain and Portugal is saturated, resulting in different market prices for Portugal: 394.776 €/MWh and 479.218 €/MWh in 2040 and 2050, respectively.

The graph 10 shows how demand in Spain increases by 59.573 TW between 2030 and 2040, and by 113.107 TW between 2040 and 2050.

Around the year 2030 the cash flows start to become positive (Figure 13). Considering that the output of new investments will increase every year, and market prices are higher it seems reasonable that the profitability of these technologies is assured. In the case of combined cycle plants, it can be seen that from 2040 onwards, which is the year in which the generation of these plants begins to decrease, income decreases, resulting in a lower cash flow. However, it remains positive, ensuring the security of supply of the system.

In Portugal, demand growth between 2030 and 2040 (around 39.979 TW) is very strong compared to the rest of the years. As in Spain, the production of combined cycle plants is significant until 2040, supplying a large part of the demand coverage. Again, cash flows from new investments are negative in the first years and then turn positive, confirming the viability of these technologies (Figure 14). Combined cycle plants decrease profit margin but still remain profitable under the conditions of this scenario.

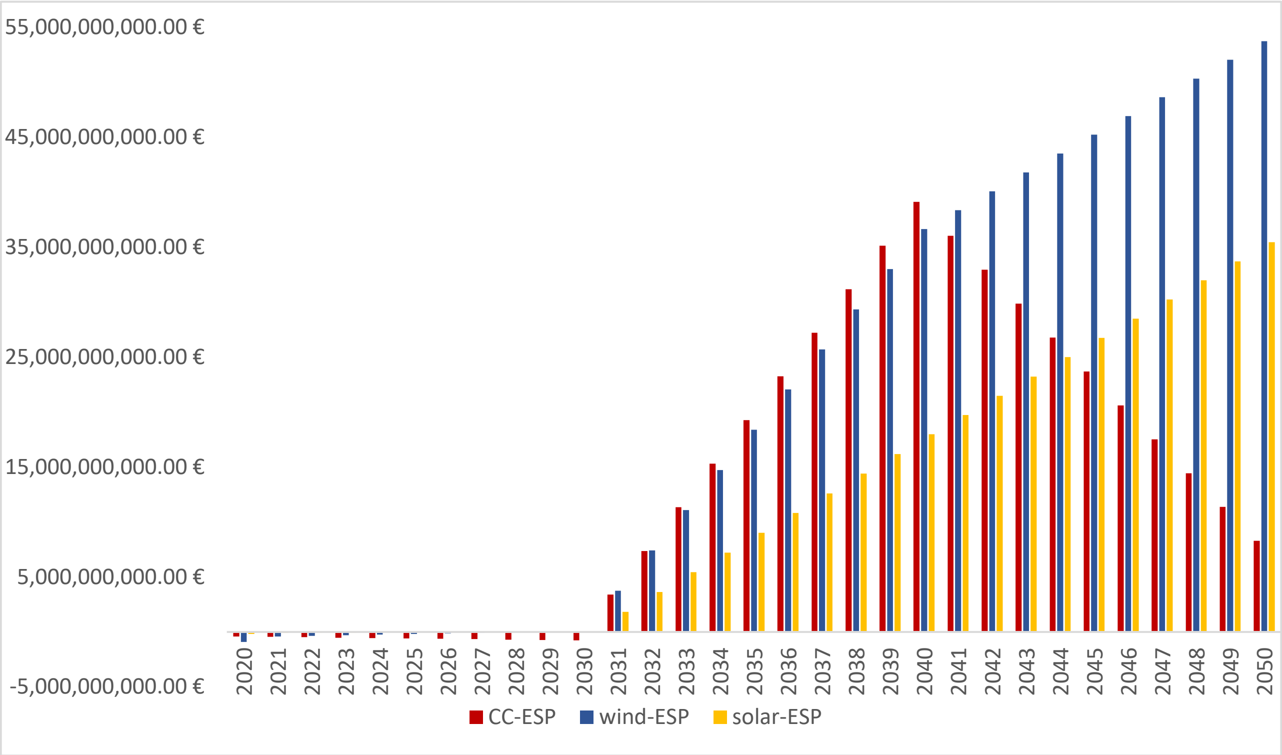


Figure 13: Annual net cash flows in Spain under the NECP scenario.

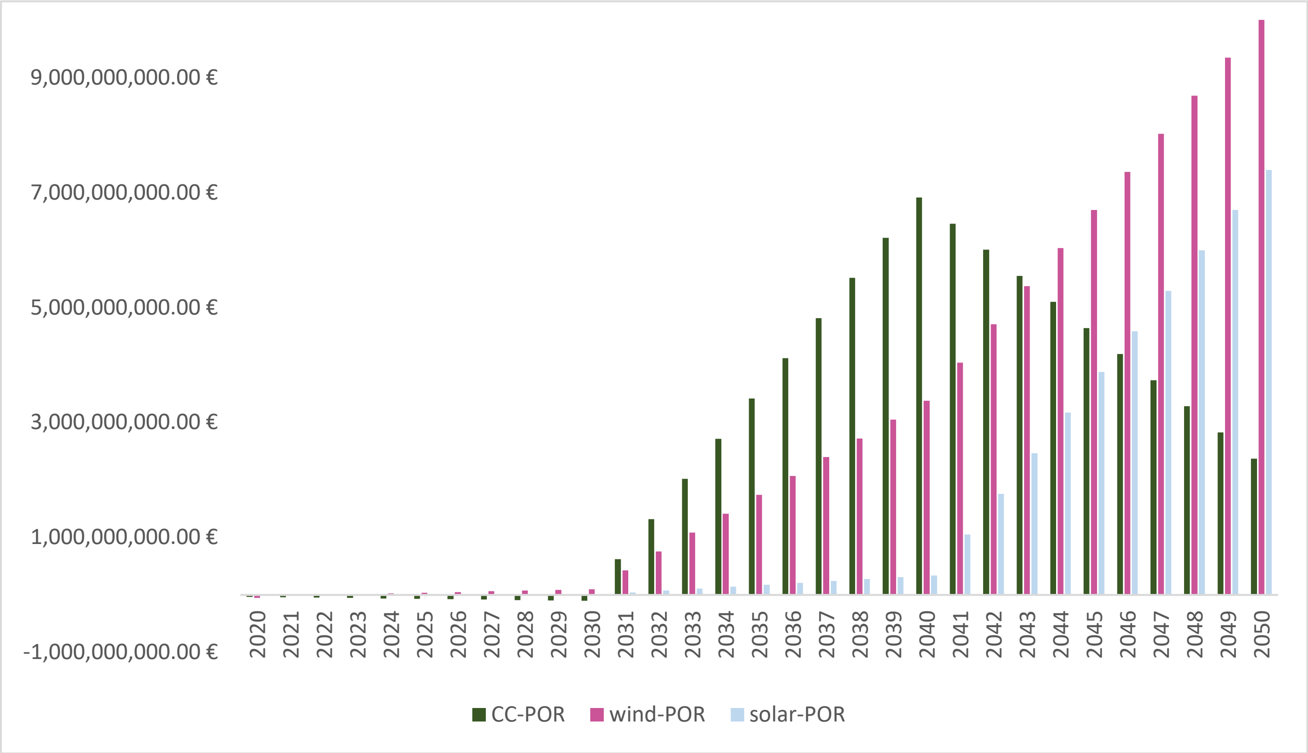


Figure 14: Annual net cash flows in Portugal under the NECP scenario.

The results of the net present value of each combined cycle unit represented in CEVESA are shown below. As can be seen in the graph 15, most of the Spanish plants show positive results due to the high revenues received through the market. The Portuguese combined cycle plants reflect profitable results with the exception of the last three (Figure 16). These results show that the vast majority of the gas-fired power plants (Annex III) that currently constitute the Iberian generating park have assured profitability in the coming years.

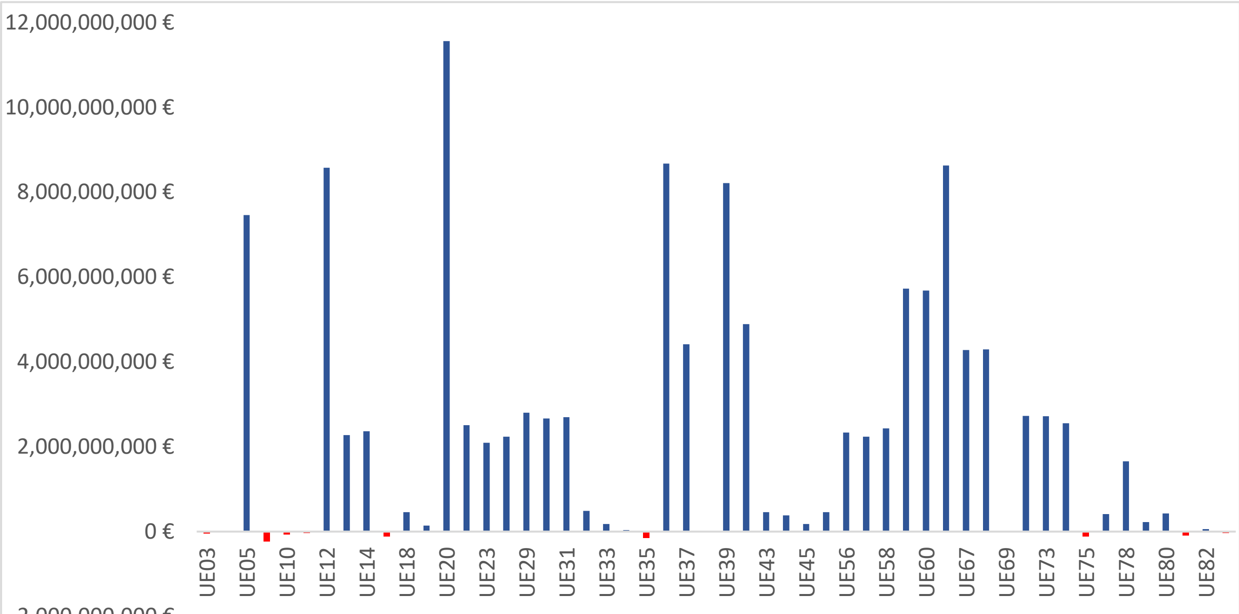


Figure 15: Net present value of combined cycle power plants in Spain under the NECP scenario.

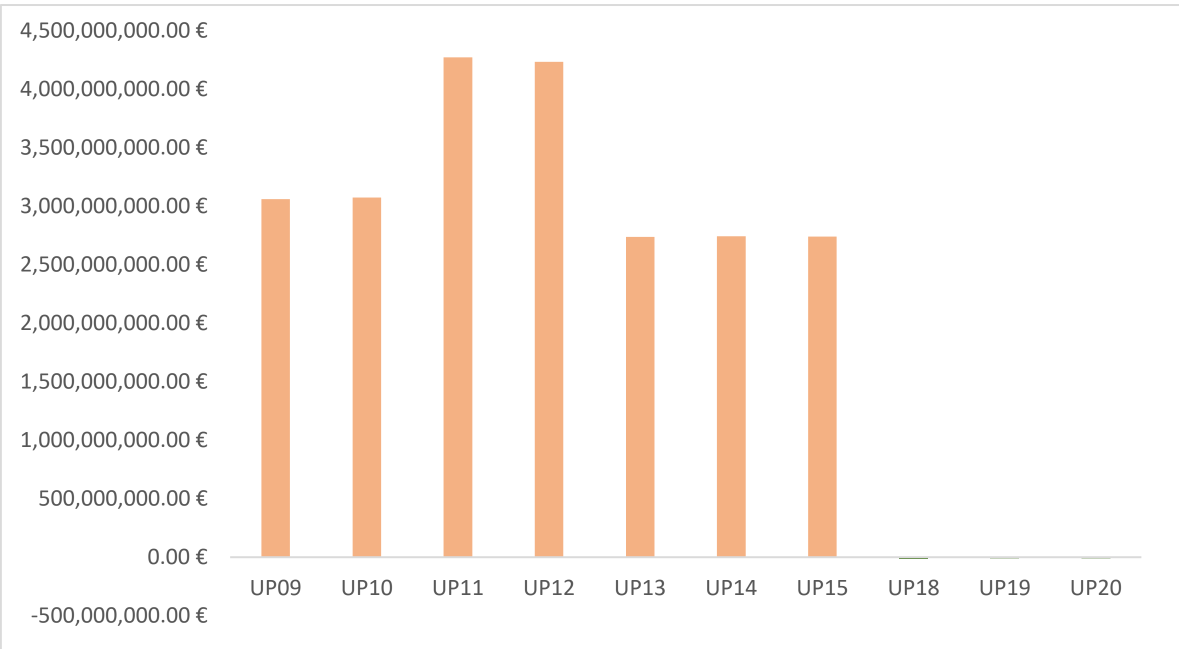


Figure 16: Net present value of combined cycle power plants in Portugal under the NECP scenario.

The following graph shows the values obtained in the LCOE calculation. Given that this parameter refers to the total costs incurred by each technology during its useful life, it is really interesting to compare different generation sources, both renewable and conventional. In this scenario, LCOE values in Spain of 23.639 €/MWh and 27.215 €/MWh were obtained for solar PV and wind power, respectively. In the case of existing gas-fired power plants, the LCOE of each one was averaged, resulting in 60.132 €/MWh. The LCOE values for the technologies in Portugal were as follows: 49.93 €/MWh for combined cycles, 16.13 €/MWh for photovoltaic panels and 21.543 €/MWh for wind energy.

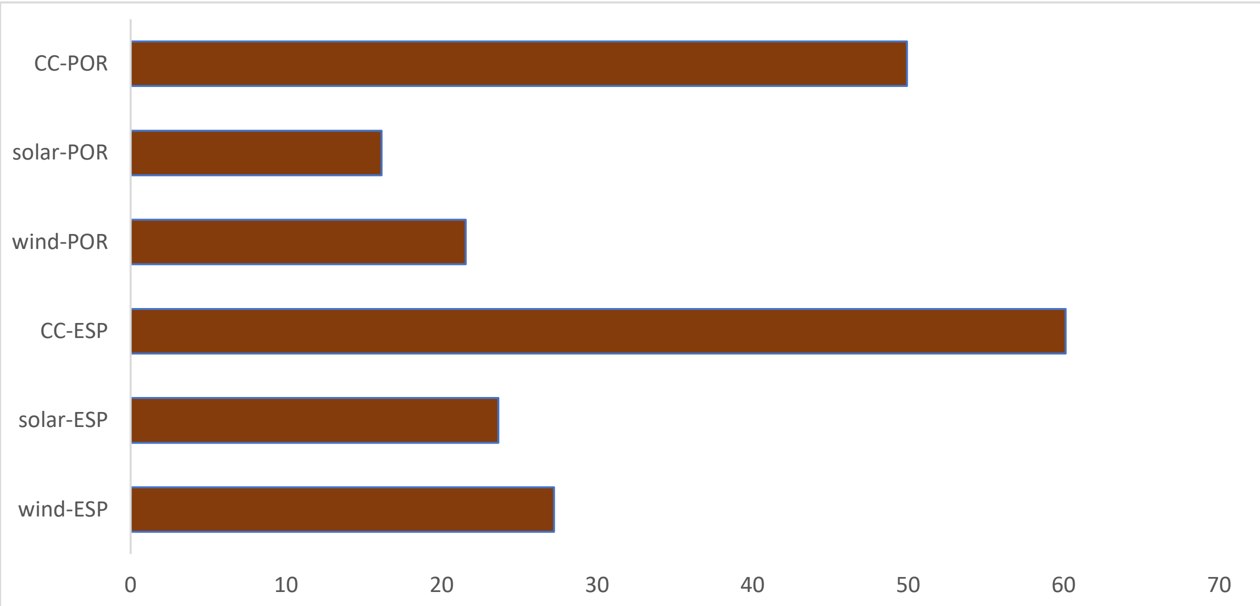


Figure 17: LCOE values for the different technologies under the INECP scenario.

In October 2020, the investment bank Lazard compared different renewable and conventional energy sources by calculating the LCOE. Considering possible cost differences within the same technology, they published the following ranges of values: between 24-35 € for solar PV; between 22-46 € for wind power and between 37-62 € for combined cycle power [51]. Comparing these figures with the values obtained from the financial model, it can be seen that with the exception of the Portuguese PV plants, the rest of the results are within the range published by Lazard. However, considering that in the coming years both operation and maintenance costs as well as investment costs in the field of renewable energies will decrease and production will increase, it is reasonable to conclude that the LCOE of these technologies will decrease and the values provided by the financial model are accurate.

Finally, the table below shows the values of the other profitability indicators obtained for each technology analysed. Once again, due to the high estimated revenues that the units will receive from 2035 onwards, the results of the net present value, the internal rate of return and the rate of return are very high. While it is noted that the profitability of renewable technologies is more than guaranteed, a more realistic analysis is needed to determine whether combined cycle power plants will continue to be viable in future years.

Columna1	NPV	IRR	LCOE	TLCC	PI
ESP-wind	167.469.583.735 €	36,49%	27,22	24.691.571.065 €	357
ESP-solar	92.686.326.673 €	45,44%	23,64	7.553.069.119 €	310
POR-wind	21.527.329.093 €	52,66%	21,54	4.347.547.770 €	303
POR-solar	9.160.949.480 €		16,13	651.891.817 €	4037
UE03	-41.936.615 €	-4,80%	81,89	97.095.528 €	-263
UE04	-14.335.862 €	2,29%	79,41	69.854.766 €	-89
UE05	7.462.632.935 €	38,54%	50,29	2.176.167.576 €	24876
UE09	-228.913.630 €		86,77	361.229.539 €	-938
UE10	-67.386.728 €		83,60	110.001.305 €	-548
UE11	-28.224.333 €	0,07%	84,73	93.442.056 €	-239
UE12	8.581.793.585 €	40,81%	40,29	2.877.707.384 €	31796
UE13	2.276.315.582 €	38,18%	44,68	838.669.217 €	20117
UE14	2.361.984.914 €	40,00%	44,97	794.667.949 €	21120
UE17	-117.444.583 €	-5,96%	88,38	260.667.563 €	-785
UE18	458.582.831 €	28,64%	63,79	159.943.179 €	4564
UE19	138.531.195 €	12,49%	73,09	254.080.165 €	1422
UE20	11.566.989.901 €	39,41%	43,42	3.456.888.057 €	35374
UE22	2.506.274.783 €	37,83%	45,88	864.186.849 €	22445
UE23	2.097.173.611 €	38,45%	44,77	777.708.047 €	19009
UE26	2.235.032.615 €	35,30%	46,57	849.538.898 €	1575
UE29	2.803.451.622 €	44,71%	43,12	902.933.091 €	21465
UE30	2.664.920.753 €	40,79%	44,00	927.518.927 €	20423
UE31	2.698.827.959 €	45,39%	42,78	856.380.146 €	20939
UE32	488.721.700 €	30,34%	60,92	151.644.337 €	4704
UE33	182.244.652 €	16,71%	70,09	179.156.357 €	1762
UE34	34.177.247 €	10,01%	79,99	111.627.414 €	263
UE35	-150.662.293 €		88,49	267.972.280 €	-908
UE36	8.679.141.291 €	40,85%	40,58	2.928.925.948 €	38323
UE37	4.419.329.373 €	35,50%	47,00	1.716.015.105 €	21248
UE38	-16.336.981 €	1,15%	81,86	67.306.074 €	-237
UE39	8.216.924.605 €	38,82%	40,92	2.834.221.621 €	39366
UE42	4.890.286.651 €	39,52%	46,09	1.670.620.958 €	9405
UE43	457.062.098 €	30,41%	60,77	143.196.759 €	4190

UE44	383.548.259 €	22,30%	65,67	202.957.336 €	3527
UE45	178.543.283 €	16,05%	70,11	186.801.686 €	1668
UE52	460.992.372 €	25,33%	64,67	194.358.305 €	2544
UE56	2.335.883.178 €	43,20%	44,02	784.905.471 €	22591
UE57	2.235.850.454 €	34,09%	46,19	884.631.342 €	20631
UE58	2.433.737.461 €	35,57%	46,19	903.954.318 €	22347
UE59	5.730.117.584 €	41,25%	42,84	1.707.978.989 €	30442
UE60	5.685.161.450 €	41,01%	42,76	1.690.761.913 €	30441
UE65	8.634.918.281 €	36,37%	41,60	3.120.665.294 €	33613
UE67	4.283.048.699 €	42,19%	40,02	1.412.025.883 €	34996
UE68	4.293.428.524 €	45,28%	39,62	1.349.046.074 €	35598
UE69	34 €	11,76%	109,15	69 €	
UE72	2.724.188.318 €	44,79%	43,59	883.849.867 €	25392
UE73	2.718.260.989 €	43,27%	43,85	874.426.537 €	25208
UE74	2.551.213.735 €	39,77%	44,04	882.865.433 €	23728
UE75	-111.265.117 €		84,45	180.329.283 €	-717
UE77	414.736.148 €	21,67%	66,93	235.856.148 €	2455
UE78	1.657.343.488 €	32,94%	71,18	352.189.879 €	9110
UE79	222.225.070 €	19,10%	68,69	170.084.604 €	2414
UE80	425.508.316 €	29,48%	59,62	156.622.791 €	4484
UE81	-93.714.468 €	-10,77%	82,78	172.236.997 €	-832
UE82	59.413.511 €	13,94%	76,46	79.624.967 €	372
UE83	-24.500.594 €	1,34%	83,31	95.867.779 €	
UP09	3.062.592.264 €	43,80%	41,01	1.594.264.815 €	19649
UP10	3.076.396.758 €	47,89%	40,93	1.582.224.086 €	19737
UP11	4.274.482.657 €	47,43%	49,80	1.400.471.149 €	18386
UP12	4.237.107.565 €	43,47%	49,90	1.398.783.361 €	18225
UP13	2.738.514.859 €	40,82%	47,11	1.118.256.674 €	27386
UP14	2.743.427.887 €	40,74%	47,18	1.111.014.994 €	27435
UP15	2.741.999.385 €	41,26%	47,51	1.079.790.278 €	26324
UP18	-13.395.250 €		59,19	13.807.473 €	-290
UP19	-12.627.186 €		59,37	13.048.907 €	-274
UP20	-12.564.767 €		57,26	12.940.847 €	-272

Table V. Results of profitability indicators under the NECP scenario.

4.2.2. Pessimistic scenario

In this pessimistic scenario, the investments made in renewable energies in 2020 to face the next decade are lower than in the NECP scenario. Specifically, the installed capacity of wind and solar photovoltaic energy in 2020 in Spain is 21468.485 MW and 7304.63

MW, respectively (Figure 18). In the previous scenario, these same values corresponded to 25257.041 MW of wind technology and 8593.682 MW of solar PV (Figure 9).

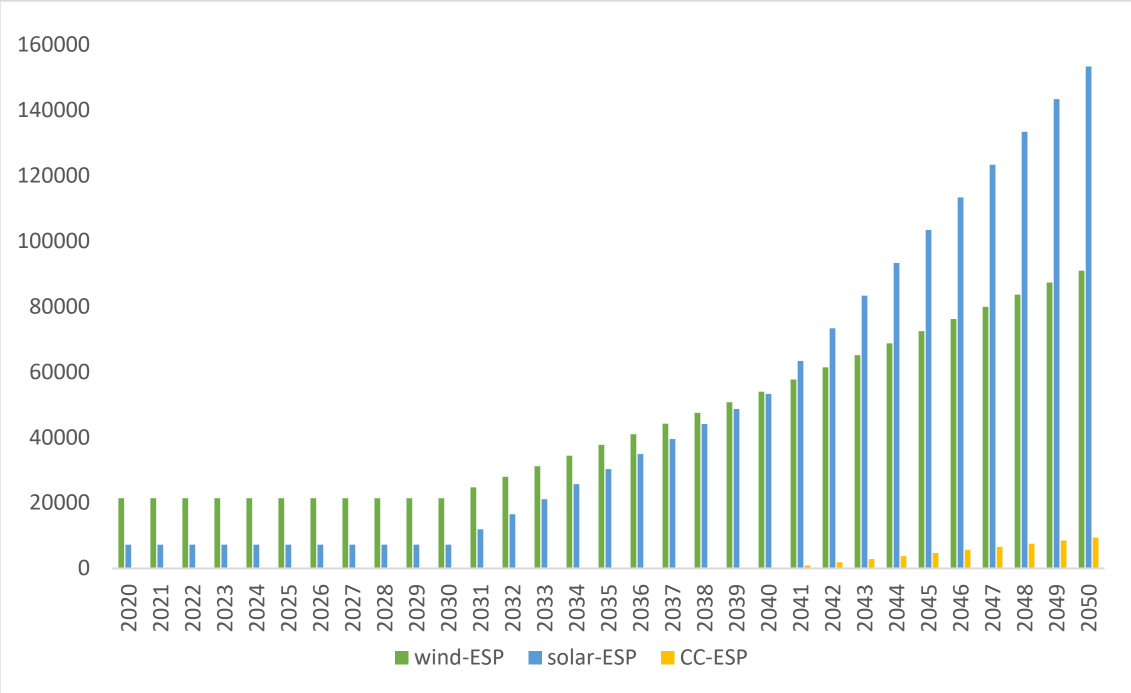


Figure 18: Evolution of accumulated installed power in Spain under the pessimistic scenario (MW).

Since the installed capacity of both types of energy in this scenario is lower, the electricity production will also be lower (Figure 19). Until 2030, Spanish wind farms contribute 44073.9 GWh annually and solar panels 7402.3 GWh. In the NECP framework the annual wind and solar production was 51851.7 GWh and 8708.6 GWh, respectively. Considering that the interannual demand variation is higher in this scenario, the generation from combined cycle power plants is much higher, peaking in 2030 with 91719 GWh compared to 86238 GWh in the baseline scenario.

From 2031 onwards, new investments are made in wind and solar photovoltaic energy in response to the continued growth in consumption and restrictions on generation from conventional power plants. Furthermore, in this scenario, the total decommissioning of Spanish nuclear power plants will not take place until 2037, favouring security of supply and allowing the reduction of generation in combined cycle plants to the benefit of new renewable technologies.

In the year 2040 there is a new, quite pronounced inter-annual variation in demand that implies a great impulse in the installation of renewable energy sources, especially photovoltaic, achieving an installed capacity of 153350.93 MW and almost 90993.14 MW of wind power in 2050. There is also some small investment in combined cycle power plants to provide security for the electricity system.

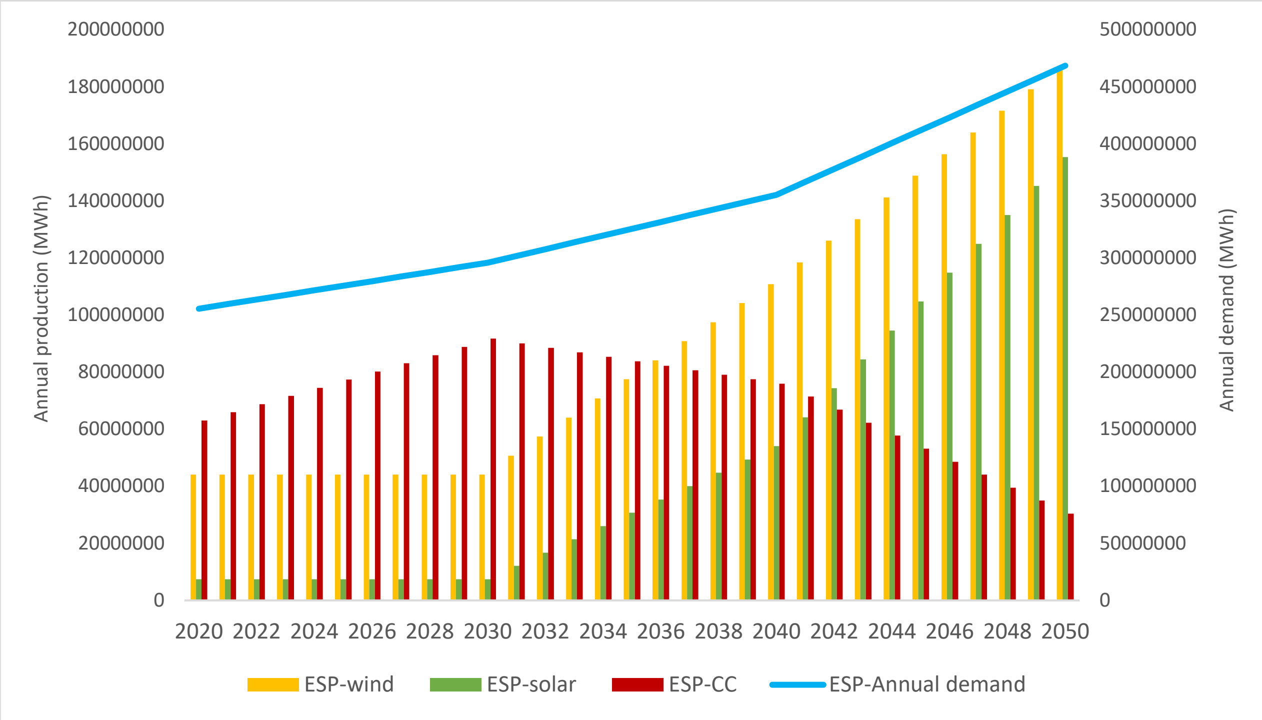


Figure 19: Annual production technologies and annual demand in Spain under the pessimistic scenario (MWh).

The situation in Portugal is similar. The installed capacity values in 2020 (Figure 20) represent 4373.25 MW of wind power and 620.5 MW of photovoltaic power compared to the 5145 MW and 730 MW of wind and solar power respectively reflected in the NECP scenario (Figure 11). As in Spain, electricity demand is higher in the pessimistic scenario, which implies higher production by gas-fired power plants (Figure 21). As in the baseline scenario, investments in new renewables do not start until 2040, so until 2044, renewable production does not overtake gas production. In 2050, the installed capacity of solar and wind farms corresponds to 16438.653 MW and 11118.445 MW, respectively. However, it is worth mentioning the investments started in 2030 in combined cycle plants and which will continue until 2040, necessary to cover the increase in demand and in anticipation of new investments in renewables.

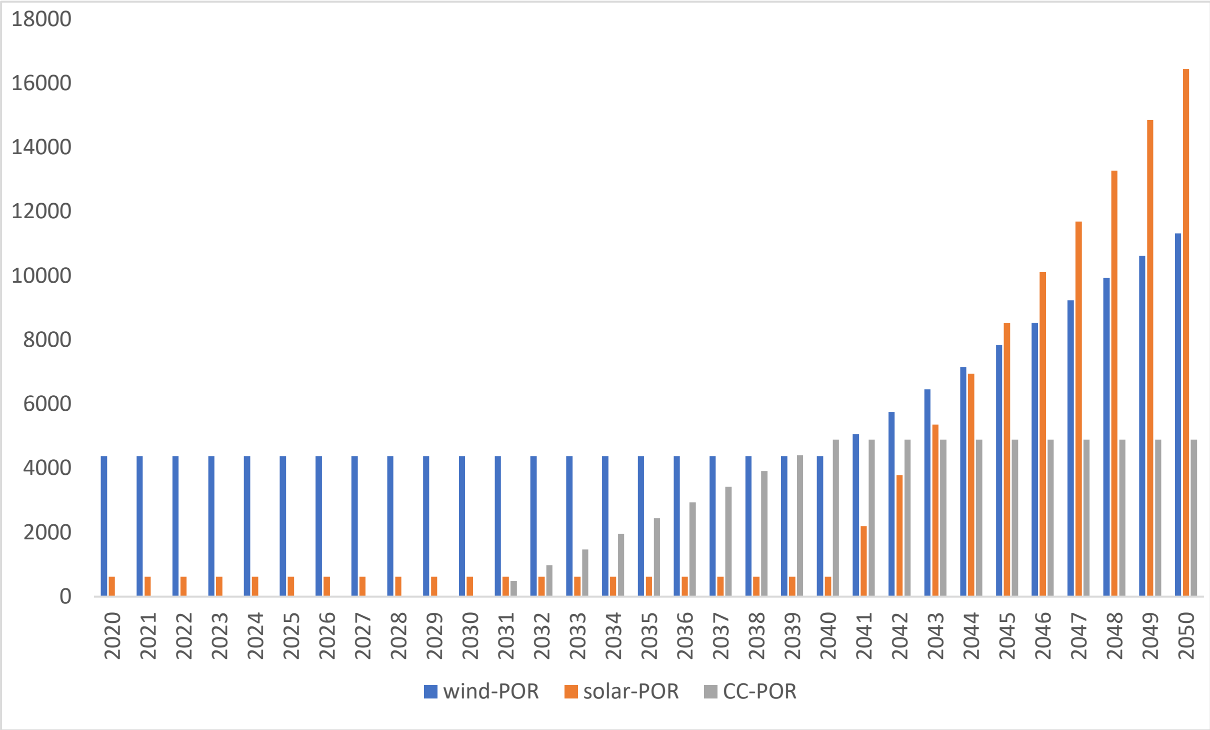


Figure 20: Evolution of accumulated installed power in Portugal under the pessimistic scenario (MW).

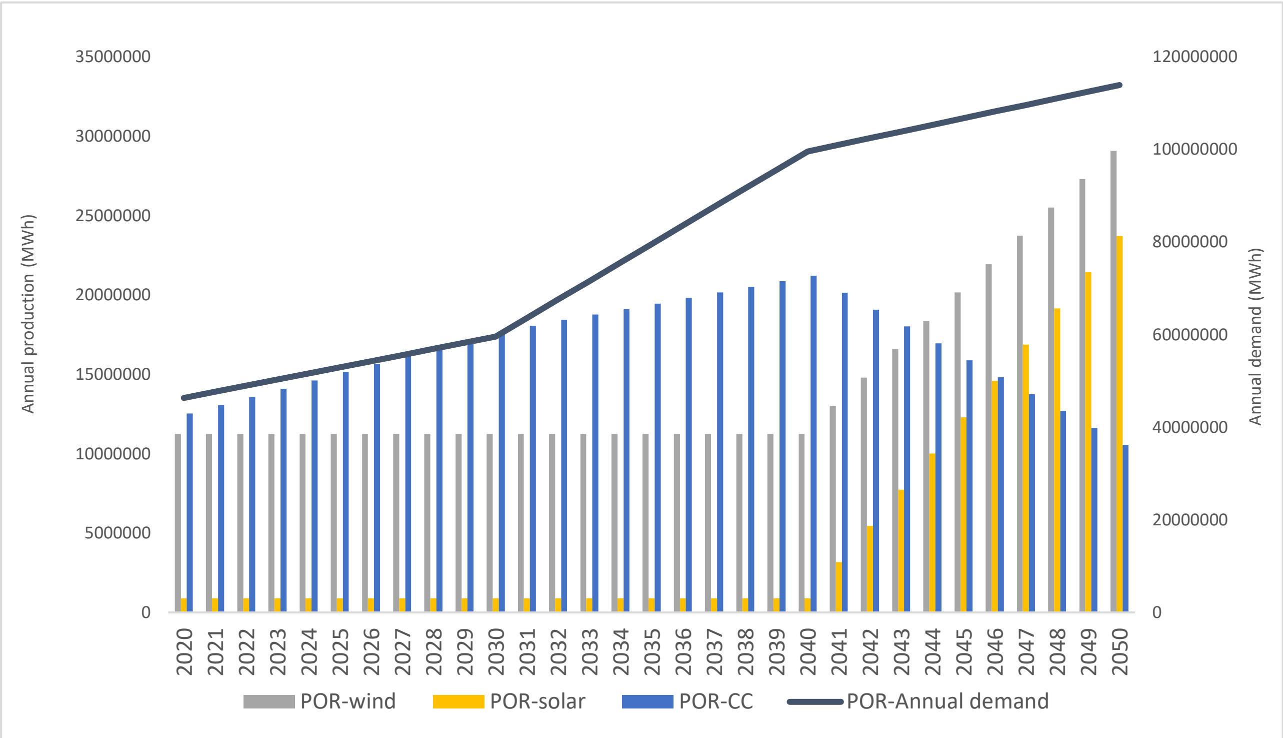


Figure 21: Annual production technologies and annual demand in Portugal under the NECP scenario (MWh).

The figure 22 shows the net cash flows of wind, solar and combined cycle plants grouped together. As in the previous scenario, cash flows remain negative until 2030 for combined cycle plants and until 2026 for the other technologies. Market prices hardly vary from those of the base scenario, although production by renewables in the early years is lower, so that investment and maintenance costs exceed revenues. Combined cycle plants obtain more cash inflows in the first 10 years, however, as fuel and CO2 costs are higher than in the previous scenario, they also take longer to obtain a positive cash flow. In 2040, with the installation of new renewable capacity contributing to a significant increase in the production of these technologies, revenues increase leading to higher cash flows compared to the base case.

The market prices provided by CEVESA for this scenario are realistic from 2020 to 2030 (between 19 and 30 €/MWh) but from new investments onwards they become very high by approaching the price of non-supplied energy. Values of 687.013 €/MWh in 2040 and 580.332 €/MWh for Spain. In Portugal market prices rise to 380.315 €/MWh in 2040 and 533.063 €/MWh.

New investments are able to recover their initial investment costs in the first years and will be profitable as their output increases over the years. Combined cycle plants, on the contrary, will have lower profits in the later years due to environmental restrictions.

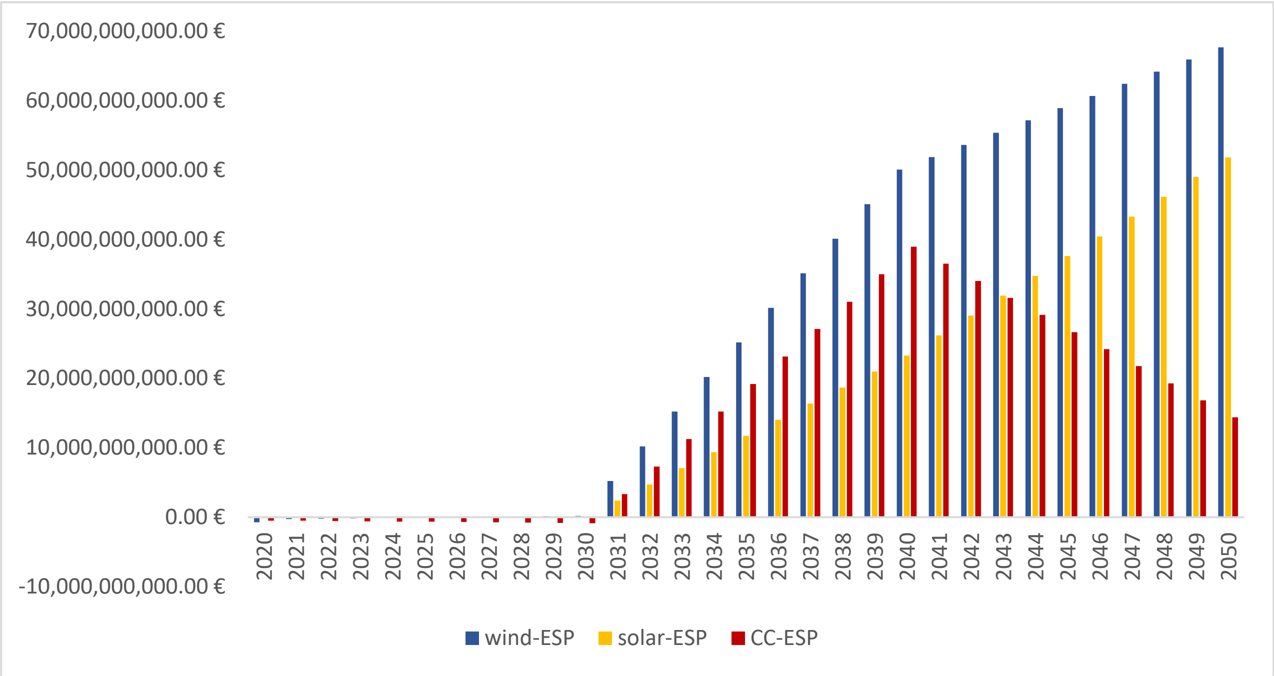


Figure 22: Annual net cash flows in Spain under the pessimistic scenario.

In Portugal, the situation is similar, although combined cycle plants show more favourable cash flows in recent years to ensure their viability (Figure 23).

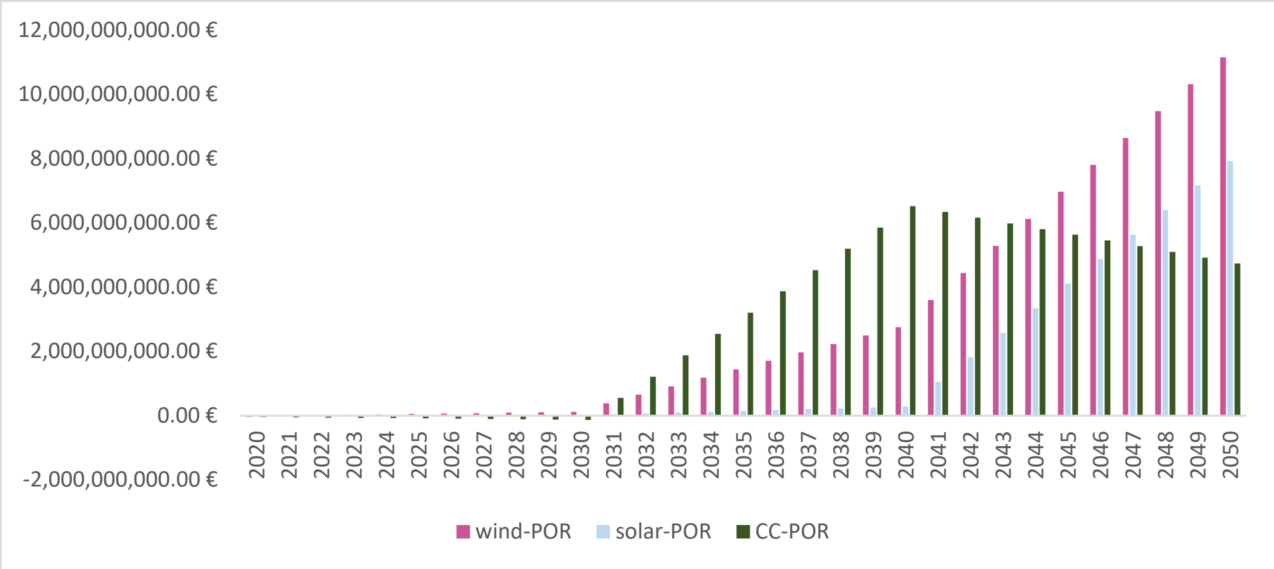


Figure 23: Annual net cash flows in Portugal under the NECP scenario.

The results of the net present value of the different combined cycle plants represented in CEVESA (Annex III) are shown below. In this scenario, given that the share of renewables in the first years is lower than in the NECP scenario and therefore the contribution of combined cycle plants to energy production is higher, their net present value is also higher. Both Spanish and Portuguese gas plants benefit from the decrease in the installation of renewable capacity.

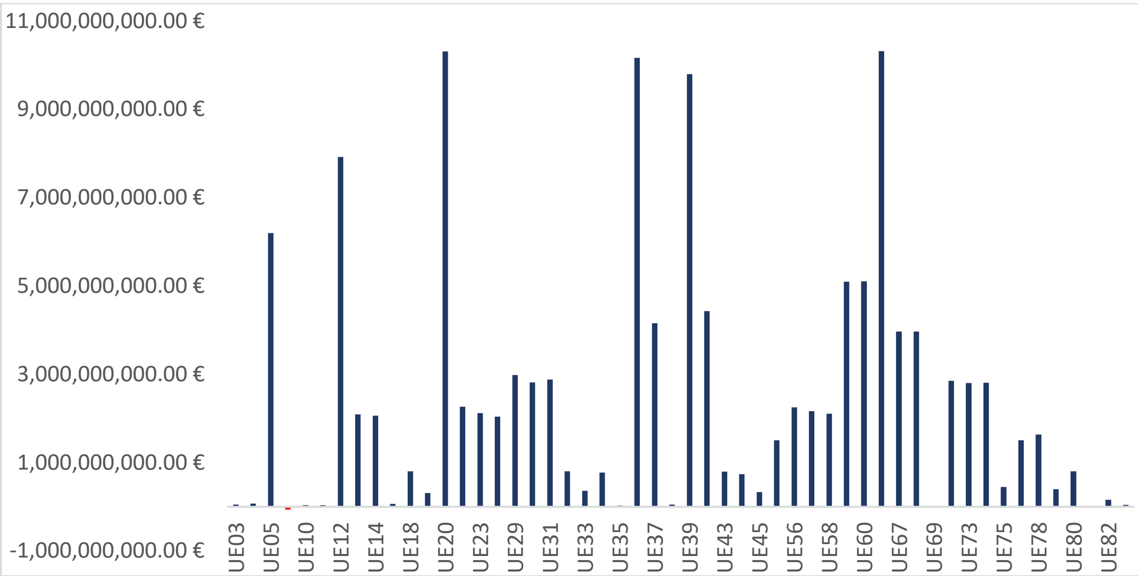


Figure 24: Net present value of combined cycle power plants in Spain under the pessimistic scenario.

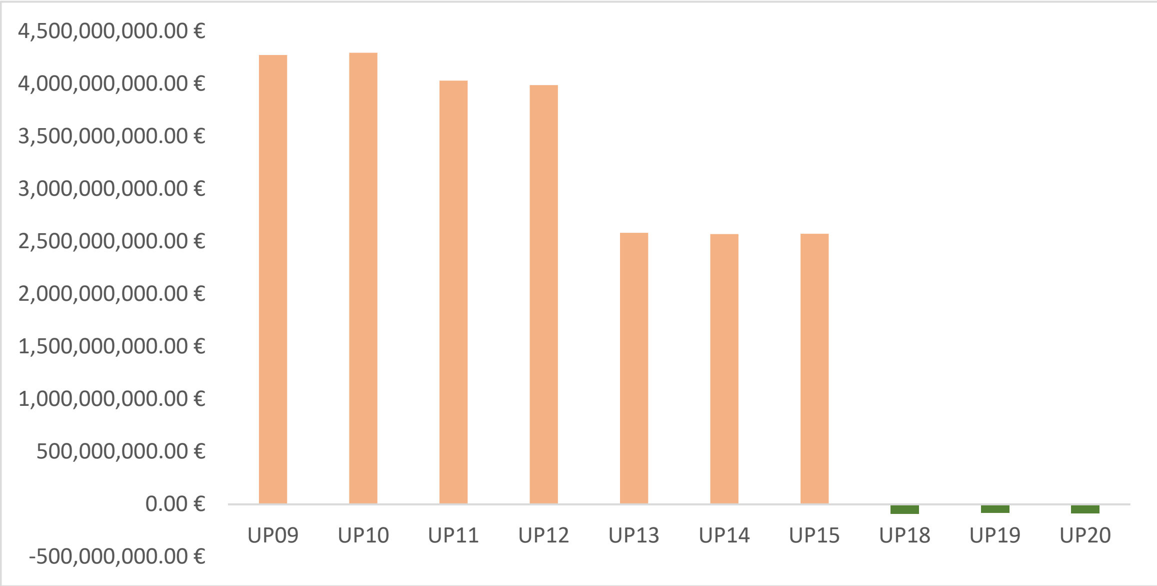


Figure 25: Net present value of combined cycle power plants in Portugal under the pessimistic scenario.

The following graph shows the LCOE results for each of the technologies analysed. In Spain, in the case of wind and solar energy, values very similar to the base scenario are obtained: 27.067 and 22.819 €/MWh, respectively. In Portugal, the situation is similar: 21.275 and 16.434 €/MWh for wind and photovoltaic technology, respectively. The average LCOE value of combined cycle in Spain is 61.751 €/MWh and 56.912 €/MWh in Portugal. The latter two figures, especially the LCOE in Portugal, are higher than in the previous scenario. It makes sense if proportionally the increase in fuel costs and emissions is higher than the increase in production. These values are still within the ranges of the estimates calculated by Lazard except again for solar energy.

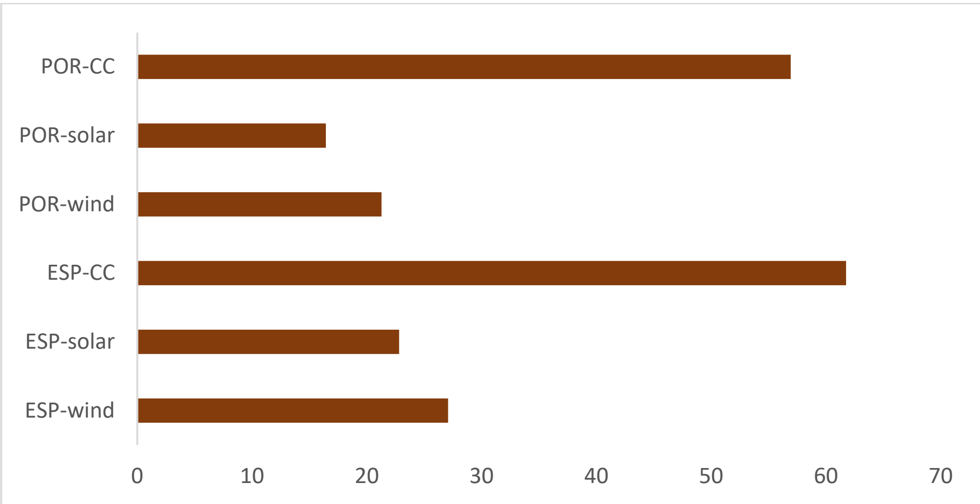


Figure 26: LCOE values for the different technologies under the pessimistic scenario.

Finally, the table with the results of the profitability indicators calculated for each generation unit applying the pessimistic scenario conditions is included. Comparing the results with those of the baseline scenario, it can be seen that the parameters are more favourable in terms of viability (higher values of NPV, IIR and PI). Therefore, the increase in demand growth that forces the plants to generate more electricity has a positive influence on their revenues. When computing revenues and costs in the financial model, it can be seen that in this scenario, despite the increase in costs (TLCC), the profit margin is higher.

In addition, in this scenario, there are likely to be more hours in which production is not able to meet demand and market prices are high, resulting in more revenues.

Columna1	NPV	IIR	LCOE	TLCC	PI
ESP-wind	224.757.277.999 €	42,73%	27,07	26.287.499.996 €	956
ESP-solar	127.068.163.205 €	53,14%	22,82	9.245.644.785 €	812
POR-wind	21.082.539.234 €	65,88%	21,28	3.740.373.909 €	1143
POR-solar	9.569.392.659 €		16,43	612.163.354 €	861
UE03	52.566.077 €	11,18%	80,76	119.182.887 €	332
UE04	73.814.956 €	14,03%	75,64	85.249.007 €	463
UE05	6.199.574.392 €	37,09%	52,20	2.355.426.240 €	20666
UE09	-57.635.932 €	3,38%	89,34	382.048.095 €	-236
UE10	39.644.060 €	10,10%	84,48	117.187.042 €	324
UE11	39.528.042 €	10,30%	83,30	109.504.727 €	337
UE12	7.922.735.839 €	38,17%	43,66	3.128.719.052 €	29355
UE13	2.092.092.190 €	35,45%	47,09	984.458.608 €	18489
UE14	2.067.324.491 €	36,35%	47,18	936.079.331 €	18486
UE17	64.743.795 €	8,78%	88,49	295.819.607 €	434
UE18	800.279.437 €	32,65%	65,05	236.409.485 €	7965
UE19	313.924.079 €	16,16%	71,79	329.540.175 €	3220
UE20	10.313.893.679 €	37,60%	46,66	3.678.135.317 €	31542
UE22	2.264.282.345 €	34,84%	48,29	1.021.866.919 €	20278
UE23	2.121.562.020 €	35,74%	47,74	956.609.193 €	19230
UE26	2.042.967.884 €	32,15%	48,83	1.003.491.670 €	1439
UE29	2.984.110.472 €	44,31%	47,04	1.074.754.636 €	22848
UE30	2.818.738.398 €	39,14%	47,82	1.077.648.678 €	21602
UE31	2.885.325.930 €	44,46%	46,18	1.046.471.172 €	22386
UE32	802.088.066 €	33,63%	62,96	226.845.488 €	7719
UE33	365.348.176 €	21,60%	68,94	236.580.931 €	3531
UE34	772.983.000 €	22,38%	86,12	253.767.410 €	5936
UE35	29.083.194 €	7,40%	88,65	285.000.249 €	176
UE36	10.165.389.683 €	37,66%	46,48	3.598.927.891 €	44885
UE37	4.155.411.184 €	33,18%	49,23	2.037.573.188 €	19979
UE38	48.296.494 €	12,82%	80,08	77.663.024 €	704

UE39	9.798.854.054 €	38,95%	46,25	3.392.932.946 €	46945
UE42	4.434.171.718 €	37,49%	48,33	1.954.597.391 €	8528
UE43	796.414.160 €	34,31%	62,93	229.428.735 €	7300
UE44	738.612.015 €	27,08%	66,65	293.098.730 €	6792
UE45	335.728.810 €	18,46%	69,54	279.661.802 €	3135
UE52	1.509.016.865 €	29,06%	72,26	441.465.297 €	8327
UE56	2.248.888.795 €	38,71%	46,66	944.388.016 €	21750
UE57	2.167.056.251 €	31,97%	48,60	1.050.023.761 €	19996
UE58	2.105.764.346 €	32,44%	48,50	1.034.148.673 €	19336
UE59	5.095.726.758 €	39,35%	45,82	1.809.976.924 €	27072
UE60	5.105.966.538 €	39,83%	45,73	1.783.015.618 €	27340
UE65	10.316.162.829 €	35,55%	47,01	3.742.561.645 €	40157
UE67	3.968.437.622 €	41,27%	43,04	1.516.304.238 €	32426
UE68	3.969.831.407 €	43,07%	42,66	1.460.995.236 €	32915
UE69	191 €	25,04%	90,48	68 €	
UE72	2.850.846.017 €	43,75%	46,78	1.034.319.106 €	26573
UE73	2.805.631.406 €	42,61%	46,91	1.020.594.954 €	26018
UE74	2.813.111.992 €	39,19%	47,54	1.072.837.839 €	26164
UE75	445.534.847 €	15,01%	88,42	295.234.648 €	2877
UE77	1.504.005.983 €	27,06%	72,88	468.994.391 €	8901
UE78	1.634.059.022 €	34,71%	70,87	393.226.822 €	8982
UE79	401.235.524 €	23,26%	66,08	229.382.191 €	4358
UE80	805.206.174 €	35,09%	60,83	246.610.535 €	8484
UE81	-21.702.769 €	4,40%	83,10	207.073.337 €	-192
UE82	162.099.107 €	21,12%	77,95	90.004.224 €	1013
UE83	40.978.381 €	10,23%	81,22	113.876.682 €	
UP09	4.273.864.221 €	43,37%	46,82	1.993.467.539 €	27419
UP10	4.292.530.659 €	46,13%	46,63	1.968.446.293 €	27539
UP11	4.027.553.814 €	51,53%	51,77	1.578.070.756 €	17324
UP12	3.985.712.408 €	42,99%	52,47	1.543.152.748 €	17144
UP13	2.581.960.377 €	39,81%	49,41	1.299.907.885 €	25820
UP14	2.570.979.332 €	38,92%	50,24	1.294.053.568 €	25710
UP15	2.573.627.066 €	38,31%	49,52	1.305.396.259 €	24707
UP18	-87.152.656 €		72,64	90.461.309 €	-1894
UP19	-81.126.392 €		73,98	84.033.730 €	-1763
UP20	-85.934.498 €		75,63	88.964.545 €	-1867

Table VI. Results of profitability indicators under the pessimistic scenario.

Chapter 5. CONCLUSIONS

New investments in renewable energy are the order of the day in the new plans promoted by the governments of many countries to contribute to the reduction of atmospheric pollution and greenhouse gas emissions. However, the transition period to a fully renewable energy electricity system faces some dilemmas. In the Iberian Peninsula, the vast majority of the renewable generation park is made up of hydro, wind, and solar photovoltaic plants. The latter two technologies are the ones with the greatest future prospects due to their advanced development and energy efficiency compared to other types of renewables. However, their unmanageable nature and the current difficulties in storing the energy they generate require the presence of other types of energy in the electricity system. For this reason, combined cycle plants have become the key technology for ensuring electricity supply at times when renewable sources are unable to produce energy. The closure of these plants is scheduled for the late 2040s, a time when some storage technologies are expected to develop significantly. However, considering the configuration of the current remuneration system for generation technologies, doubts arise as to the profitability of gas-fired plants in the coming years.

This analysis has focused on determining the profitability of new investments in renewable energies (wind and solar photovoltaic) and existing combined cycle power plants under a scenario of emission restrictions. This simulation mode emphasises investments in renewables to replace conventional generation. This situation can lead to periods when demand is not met, and the marginal cost of the market approaches the price of the energy not supplied. These values, which are equivalent to the market price of the technologies, are high, resulting in increased revenues. Therefore, the profit margin of the technologies is higher than it would be in a scenario without emission restrictions.

Therefore, the results achieved do not accurately represent reality, but they can give an idea of the economic situation of the technologies under a situation of emission restrictions. Hence, future analyses should try to provide values that are more in line with real market prices in order to be able to define more rigorously the viability of the different generation units.

One aspect to be highlighted is the new implementation in Spain of a capacity market with the aim of encouraging investment in storage and guaranteeing supply in the national electricity system. This mechanism could be key to avoiding the bankruptcy of some combined cycle plants.

To summarise, the results of the study show the high profitability of renewable technologies in both scenarios. Even in the pessimistic scenario they are able to recover investment costs and generate large profits. Furthermore, the future perspectives for renewable energies are increasingly lower installation costs and higher capacity factors. The biggest problem is for combined cycle power plants, as not all of them have positive cash flows. In the pessimistic scenario, the lower installed capacity of renewables together with a higher interannual change in demand contributes to an increase in production by gas-fired plants. This situation results in higher profitability of back-up technologies. It is clear that in such a scenario with high market prices, most CCGT plants are able to recover their costs. The question arises whether in a scenario without restrictions on CO2 emissions and with lower market prices they could also make a profit and not jeopardise security of supply. Consequently, it is important that combined cycle plants can participate in the capacity market so that they can receive incentives based on their availability, as renewables already do.

BIBLIOGRAPHY

[1] «Avance del Informe del sistema eléctrico español 2020 | Red Eléctrica de España». https://www.ree.es/es/datos/publicaciones/informe-anual-sistema/avance-del-informe-del-sistema-electrico-espanol-2020 (accedido may 26, 2021).

[2] «España inicia su adiós del carbón: las eléctricas apagan esta noche siete centrales térmicas». https://elperiodicodelaenergia.com/espana-inicia-su-adios-del-carbon-las-electricas-apagan-esta-noche-ocho-centrales-termicas/ (accedido may 26, 2021).

[3] «España pisa el acelerador del cierre de las centrales de carbón», *La Vanguardia*, dic. 14, 2020. https://www.lavanguardia.com/economia/20201214/6118126/apaga-llama.html (accedido may 26, 2021).

[4] «2021-04-27112258_4c65f7f1-2e56-4968-a1af-585420fa64e0$$c021e4a7-cd34-4540-8dc0-61aff419af11$$1b092c7f-55ce-4469-aea7-b08ff1b8717c$$en_gb__file$$pt$$1.pdf». Accedido: jun. 15, 2021. [En línea]. Disponible en: https://www.ren.pt/files/2021-04/2021-04-27112258_4c65f7f1-2e56-4968-a1af-585420fa64e0$$c021e4a7-cd34-4540-8dc0-61aff419af11$$1b092c7f-55ce-4469-aea7-b08ff1b8717c$$en_gb__file$$pt$$1.pdf

[5] A. Lusa, «Central de Sines encerra esta sexta-feira, antes do previsto devido a evolução do mercado», *Observador*. https://observador.pt/2021/01/15/central-de-sines-encerra-esta-sexta-feira-antes-do-previsto-devido-a-evolucao-do-mercado/ (accedido jun. 15, 2021).

[6] «Así funciona el mercado eléctrico en España – El Periodico de la Energía | El Periodico de la Energía con información diaria sobre energía eléctrica, eólica, renovable, petróleo y gas, mercados y legislación energética.» https://elperiodicodelaenergia.com/asi-funciona-el-mercado-electrico-en-espana/ (accedido may 26, 2021).

[7] E. y Sociedad, «6.1. Formación de precios en el mercado mayorista diario de electricidad | Energía y Sociedad». http://www.energiaysociedad.es/manenergia/6-1-formacion-de-precios-en-el-mercado-mayorista-diario-de-electricidad/ (accedido feb. 02, 2021).

[8] «¿Cuál es el futuro de la energía nuclear en España? - Agenda Pública». https://agendapublica.es/cual-es-el-futuro-de-la-energia-nuclear-en-espana/ (accedido may 26, 2021).

[9] «Los ciclos combinados y la eólica en el mix de electricidad español - AleaSoft Energy Forecasting». https://aleasoft.com/es/ciclos-combinados-eolica-mix-electricidad-espannol/ (accedido may 26, 2021).

[10] S. D. Martinez, Fco. A. Campos Fernandez, M. R. Abbad, y J. villar Collado, «Joint Centralized and Distributed Electricity Generation Expansion in a Decarbonized Scenario: The Spanish Case», en *2018 15th International Conference on the European Energy Market (EEM)*, jun. 2018, pp. 1-5. doi: 10.1109/EEM.2018.8469911.

[11] J. Villar, E. Salas, y A. Campos, «Combined Penetration of Wind and Solar Generation with Plug-in Electric Vehicles», *Energy Procedia*, vol. 106, pp. 59-72, dic. 2016, doi: 10.1016/j.egypro.2016.12.105.

[12] R. Castañón, A. Campos, S. Doménech Martínez, y J. Villar, «An Electricity Generation Expansion Model with ICEV and PEV Investments», jun. 2018, pp. 1-5. doi: 10.1109/EEM.2018.8469772.

[13] «Financiación». https://www.enresa.es/esp/inicio/conozca-enresa/financiacion (accedido jun. 18, 2021).

[14] «Fano - actual del sistema eléctrico español.pdf». Accedido: jun. 05, 2021. [En línea]. Disponible en: https://www.cofis.es/pdf/fys/fys13/fys13_10-17.pdf

[15] M. T. C. Campi, «EVOLUCIÓN DEL SECTOR ELÉCTRICO ESPAÑOL (1975-2015)», p. 18.

[16] «Ciclos combinados en España o cómo desperdiciar 13.100 millones». https://elperiodicodelaenergia.com/ciclos-combinados-en-espana-o-como-desperdiciar-13-100-millones/ (accedido jun. 04, 2021).

[17] Anonymous, «Acuerdo de París», *Acción por el Clima - European Commission*, nov. 23, 2016. https://ec.europa.eu/clima/policies/international/negotiations/paris_es (accedido jun. 05, 2021).

[18] «Red eléctrica: potencia instalada en España en 2020», *Statista*. https://es.statista.com/estadisticas/993769/potencia-electrica-instalada-en-espana/ (accedido jun. 05, 2021).

[19] «1603359_8.pdf». Accedido: jun. 18, 2021. [En línea]. Disponible en: https://www.cnmc.es/sites/default/files/1603359_8.pdf

[20] A. N. Nunes, «Energy changes in Portugal. An Overview of the Last Century», *Méditerranée Rev. Géographique Pays Méditerranéens J. Mediterr. Geogr.*, n.º 130, Art. n.º 130, sep. 2018, doi: 10.4000/mediterranee.10113.

[21] «APREN - Potência». https://www.apren.pt/pt/energias-renovaveis/potencia (accedido jun. 18, 2021).

[22] Viaintermedia.com, «Panorama - Así funciona el mercado eléctrico español», *Energías Renovables, el periodismo de las energías limpias*. https://www.energias-renovables.com/panorama/asi-funciona-el-mercado-electrico-espanol-20191007 (accedido jun. 05, 2021).

[23] E. y Sociedad, «6.1. Formación de precios en el mercado mayorista diario de electricidad | Energía y Sociedad». http://www.energiaysociedad.es/manenergia/6-1-formacion-de-precios-en-el-mercado-mayorista-diario-de-electricidad/ (accedido jun. 05, 2021).

[24] «informe_anual_2020_es.pdf». Accedido: jun. 15, 2021. [En línea]. Disponible en: https://www.omie.es/sites/default/files/2021-01/informe_anual_2020_es.pdf

[25] «Conclusiones principales: Costos de generación de energía renovable en 2019», p. 2.

[26] «España se afianza entre los diez principales países para la inversión en renovables». https://www.ey.com/es_es/news/2021/05/espana-se-afianza-entre-los-diez-principales-paises-para-la-inversion-en-renovables (accedido jun. 24, 2021).

[27] elEconomista.es, «Una transición ecológica que pasa necesariamente por los ciclos combinados - elEconomista.es». https://www.eleconomista.es/opinion-blogs/noticias/11104614/03/21/Una-transicion-ecologica-que-pasa-necesariamente-por-los-ciclos-combinados.html (accedido jun. 24, 2021).

[28] «Ciclos combinados, nuevo problema para Nadal: los pagos por capacidad acaban en junio». https://elperiodicodelaenergia.com/ciclos-combinados-nuevo-problema-para-nadal-los-pagos-por-capacidad-acaban-en-junio/ (accedido jun. 24, 2021).

[29] «Ministerio para la Transición Ecológica y el Reto Demográfico - DetalleParticipacionPublica». https://energia.gob.es/es-es/Participacion/Paginas/DetalleParticipacionPublica.aspx?k=409 (accedido jun. 24, 2021).

[30] «El mecanismo de capacidad y la seguridad de suministro del sistema eléctrico». https://www.ey.com/es_es/power-utilities/el-mecanismo-de-capacidad-y-la-seguridad-de-suministro-del-sistema-electrico (accedido jun. 24, 2021).

[31] «Ministerio para la Transición Ecológica y el Reto Demográfico - Primera subasta para el otorgamiento del régimen económico de energías renovables». https://energia.gob.es/electricidad/energias-renovables/convocatorias/Paginas/1subasta-otorgamiento-regimen-economico.aspx (accedido jun. 24, 2021).

[32] «El Gobierno celebrará a lo largo de 2021 nuevas subastas de renovables y de capacidad». https://elperiodicodelaenergia.com/el-gobierno-celebrara-a-lo-largo-de-2020-nuevas-subastas-de-renovables/ (accedido jun. 24, 2021).

[33] R. Menéndez, A. Martín, L. Varela-Candamio, y M. T. García-Álvarez, «AN ENHANCED TECHNO-ECONOMIC ANALYSIS OF LCOE: PUBLIC INCENTIVES VS PRIVATE INVESTMENT», *Technol. Econ. Dev. Econ.*, vol. 27, pp. 1-23, feb. 2020, doi: 10.3846/tede.2020.11259.

[34] «The thermodynamic and economic characteristics of the modern combined cycle power plant with gas turbine steam cooling - ScienceDirect». https://www.sciencedirect.com/science/article/abs/pii/S0360544218316086 (accedido jun. 06, 2021).

[35] G. Locatelli y M. Mancini, «Small–medium sized nuclear coal and gas power plant: A probabilistic analysis of their financial performances and influence of CO2 cost», *Energy Policy*, vol. 38, n.º 10, pp. 6360-6374, oct. 2010, doi: 10.1016/j.enpol.2010.06.027.

[36] C.-S. Hong y E.-B. Lee, «Power Plant Economic Analysis: Maximizing Lifecycle Profitability by Simulating Preliminary Design Solutions of Steam-Cycle Conditions», *Energies*, vol. 11, n.º 9, Art. n.º 9, sep. 2018, doi: 10.3390/en11092245.

[37] F. Martinez, A. Campos, S. Doménech, y J. Villar, «Profitability Analysis of Spanish CCGTs under Future Scenarios of high RES and EV Penetration», en *2019 16th International Conference on the European Energy Market (EEM)*, sep. 2019, pp. 1-5. doi: 10.1109/EEM.2019.8916354.

[38] «DIA-5-Evaluación-de-Proyectos-renovables-y-eficiencia-energética.pdf». Accedido: jun. 18, 2021. [En línea]. Disponible en: https://feriaexposolar.com/wp-content/uploads/2019/03/DIA-5-Evaluaci%C3%B3n-de-Proyectos-renovables-y-eficiencia-energ%C3%A9tica.pdf

[39] «Guidebook for Project Developers for Preparing Renewable Energy Investments Business Plans», p. 52.

[40] «Unlevered Free Cash Flow (UFCF)». https://www.investopedia.com/terms/u/unlevered-free-cash-flow-ufcf.asp (accedido jun. 20, 2021).

[41] «Información general - Agencia Tributaria». https://www.agenciatributaria.es/AEAT.internet/Inicio/La_Agencia_Tributaria/Aduanas_e_Impuestos_Especiales/_Presentacion/Impuestos_medioambientales/_IMPUESTOS/Impuesto_sobre_el_valor_de_la_produccion_de_la_energia_electrica/_INFORMACION/_Informacion_general_/_Informacion_general_.shtml (accedido jun. 17, 2021).

[42] «5.2 Tipos impositivos vigentes - Agencia Tributaria». https://www.agenciatributaria.es/AEAT.internet/Inicio/Ayuda/Manuales__Folletos_y_Videos/Manuales_de_ayuda_a_la_presentacion/Ejercicio_2018/_Ayuda_Modelo_200/05_Tipo_de_gravamen/5_02_Tipos_impositivos_vigentes/5_02_Tipos_impositivos_vigentes.html (accedido jun. 20, 2021).

[43] A. de, «O futuro exige uma análise de confiança Guia Fiscal 202», p. 204.

[44] https://www.energiza.org/index.php?option=com_k2&view=item&id=979:centrales-de-ciclo-combinado-en-espa%C3%B1a (Accedido jun. 25, 2021).

[45] «Deloitte-ES-Energia-cuadernos-energia-n54.pdf». Accedido: jun. 20, 2021. [En línea]. Disponible en: https://www2.deloitte.com/content/dam/Deloitte/ec/Documents/deloitte-analytics/Estudios/Deloitte-ES-Energia-cuadernos-energia-n54.pdf

[46] «Vista de Diferencias entre WACC deflactado y WACC real: use el deflactado | Cuadernos Latinoamericanos de Administración». https://revistas.unbosque.edu.co/index.php/cuaderlam/article/view/1163/730 (accedido jun. 20, 2021).

[47] «pnieccompleto_tcm30-508410.pdf». Accedido: jun. 30, 2021. [En línea]. Disponible en: https://www.miteco.gob.es/images/es/pnieccompleto_tcm30-508410.pdf

[48] «pt_final_necp_main_pt.pdf». Accedido: jun. 30, 2021. [En línea]. Disponible en: https://ec.europa.eu/energy/sites/ener/files/documents/pt_final_necp_main_pt.pdf

[49] A. R. de Oliveira *et al.*, «Joint analysis of the Portuguese and Spanish NECP for 2021-2030», en *2020 17th International Conference on the European Energy Market (EEM)*, sep. 2020, pp. 1-6. doi: 10.1109/EEM49802.2020.9221957.

[50] «Las renovables temen la 'canibalización' ante el nuevo boom: prefieren subastas con precio suelo a reformar el mercado eléctrico». https://elperiodicodelaenergia.com/las-renovables-temen-la-canibalizacion-ante-el-nuevo-boom-prefieren-subastas-con-suelo-a-reformar-el-mercado-electrico/ (accedido jul. 06, 2021).

[51] D. Ray, «Lazard's Levelized Cost of Energy Analysis—Version 13.0», p. 21, 2020.

[52] «Desarrollo Sostenible – United Nations Sustainable Development Sites». https://www.un.org/sustainabledevelopment/es/ (accedido jun. 28, 2021).

ANNEXES

Annex I. Spanish combined cycle power plants.

Thermal power plant	Province	Cycles	Investment (M€)	Owners	Power (MW)	Cost per MW (M€/MW)	Year
Aceca	Toledo	2	500	Iberdrola (50%), Gas Natural Fenosa (50%)	758,6	0,6591	2005/2006
Bahía de Algeciras	Cádiz	2	400	Repsol (100%)	820,5	0,4875	2011
Bizkaia Energía S L (Boroa)	Vizcaya	2	390	Castleton Commodities International (100%)	786,4	0,4959	2005
Arcos de la Frontera	Cádiz	5	800	Iberdrola (100%)	1585,2	0,5047	2005
Arrúbal	La Rioja	2	360	CountorGlobal (100%)	784,6	0,4588	2005
Bahía de Bizkaia	Vizcaya	2	260	BP (75%), EVE (25%)	785,3	0,3311	2003
Besós III	Barcelona	2	360	Gas Natural Fenosa (50%), Endesa (50%)	811,6	0,4436	2002
Besós V	Barcelona	2	436	Endesa (100%)	859	0,5076	2011
Campo de Gibraltar	Cádiz	2	370	Gas Natural Fenosa (50%), Cepsa (50%)	780,5	0,4741	2004
Cristóbal Colón	Huelva	1	2185	Endesa (100%)	390,9	5,5897	2006
Cartagena	Murcia	3	600	Naturgy (100%)	1248,7	0,4805	2006
Castejón 1 y 3	Navarra	2	375	TOTAL España (100%)	843,3	0,4447	2002/2008
Castejón 2	Navarra	1	180	Iberdrola (100%)	378,9	0,4751	2003
Castellón	C. Valenciana	2	625	Iberdrola (100%)	1621,3	0,3855	2002/2008
Castelnou		2	320	Electrabel (100%)	790,6	0,4048	2006
Escatrón	Zaragoza	2	400	Repsol (100%)	1078,9	0,3707	2011

Escombreras	Murcia	2	800	Iberdrola (100%)	815,6	0,9809	2005
Engie Energía Cartagena (El Fangal)	Murcia	3	500	Engie Iberia (100%)	1199,1	0,4170	2006
Campanillas	Málaga	1	250	Gas Natural Fenosa (100%)	415,5	0,6017	2011
Palos de la Frontera	Huelva	3	520	Naturgy (100%)	1166,8	0,4457	2007
Puerto de Barcelona	Barcelona	2	500	Naturgy (100%)	866,2	0,5772	2007
Puentes de García Rodríguez	La Coruña	2	367	Endesa (100%)	855,6	0,4289	2008
Plana del Vent	Tarragona	2	360	Alpiq (100%)	834,1	0,4316	2007
Sagunto	C. Valenciana	3	478	Gas natural Fenosa (100%)	1232,1	0,3880	2007
Sabón	La Coruña	1	221,3	Naturgy (100%)	391,3	0,5656	2008
Soto de Rivera	Asturias	2	484	HC Energia (100%)	854,1	0,5667	2008/2010
San Roque	Cádiz	2	340	Endesa (50%), Gas Natural Fenosa (50%)	791,6	0,4295	2002
Santurce	Vizcaya	1	180	Iberdrola (100%)	396,4	0,4541	2005
Tarragona Power	Tarragona	1	267	Iberdrola (100%)	416,9	0,6404	2003

Annex II. Portuguese combined cycle power plants.

Thermal power plant	Region	Cycles	Investment (M€)	Owners	Power (MW)	Cost per MW (M€/MW)	Year
Lares	Coimbra	2	430	EDP (100%)	870	0,494252874	2009
Pego	Medio Tejo	2	600	Elecgás-EGF Suez (50%), Endesa (50%)	837,2	0,71667463	2011
Ribatejo	Leziria do Tejo	3	500	EDP (100%)	1176	0,425170068	2004/2006
Turbogas		3	460		1032	0,445736434	1999

Annex III. UOF code of the combined cycle plants represented in CEVESA.

UOF code	Name of the power plant
UE03	ACE3
UE04	ACE4
UE05	ALG3
UE09	AMBIETA
UE10	ARCOS1
UE11	ARCOS2
UE12	ARCOS3
UE13	ARRU1
UE14	ARRU2
UE17	BAHIAB
UE18	BES3
UE19	BES4
UE20	BES5
UE22	CAMGI10
UE23	CAMGI20
UE26	COL4
UE29	CTGN1
UE30	CTGN2
UE31	CTGN3
UE32	CTJON1
UE33	CTJON2
UE34	CTJON3
UE35	CTN3
UE36	CTN4
UE37	CTNU
UE38	ECT2
UE39	ECT3
UE42	ESC6
UE43	ESCCC1
UE44	ESCCC2
UE45	ESCCC3
UE52	MALA1
UE56	PALOS1
UE57	PALOS2
UE58	PALOS3
UE59	PBCN1
UE60	PBCN2
UE65	PGR5
UE67	PVENT1
UE68	PVENT2
UE69	RABIDA2
UE72	SAGU1
UE73	SAGU2

UE74	SAGU3
UE75	SBO3
UE77	SRI4
UE78	SRI5
UE79	SROQ1
UE80	SROQ2
UE81	STC4
UE82	TAPOWER
UE83	TARRAG
UP09	LARES1
UP10	LARES2
UP11	PEGO3
UP12	PEGO4
UP13	RIBATE1
UP14	RIBATE2
UP15	RIBATE3
UP18	RTG01
UP19	RTG02
UP20	RTG03

Annex IV. Sustainable development goals.

In 2015, all Member States of the United Nations adopted the 17 Sustainable Development Goals (SDG) as part of the 2030 Agenda, which establishes a plan to achieve the goals in 15 years [52]. Each goal presents a set of integrated targets covering the economic, social, and environmental spheres.

The most prominent themes of the SDGs include ending poverty, eradicating hunger, ensuring human health and well-being as well as quality education, ensuring access to energy and water, acting against climate change, and promoting peace and justice.

The SDG that relates to energy generation and the development of an efficient, clean, and sustainable electricity system is SDG 7. In addition, country-driven actions to achieve the above goals relate to SDGs 13 and 17.

Goal 7: Ensuring access to affordable, secure, sustainable, and modern energy.

Figure x: Goal 7: Affordable and clean energy. Source: UN

Energy is becoming increasingly sustainable and available, while energy efficiency is improving, and the penetration of renewable energy continues to grow. These targets are intended to be achieved through the PNECs developed by each EU member state.

The current and future focus is on clean energies such as wind and solar to achieve a climate-neutral Europe by 2050. In addition, most conventional technologies which use coal, oil and fuel oil as fuel are destined to disappear in the near future. These types of energy are no longer cost-effective due to high emissions and fuel costs. Renewable energies, however, have greatly reduced their investment costs, demonstrating the favourable future prospects for their economic viability.

Therefore, the targets of goal 7, which are aligned with the PNECs, are to achieve a significant increase in the share of renewable energy in the total energy mix between now and 2030, to double the global rate of improvement in energy efficiency and to ensure universal access to affordable and reliable energy sources. It also aims to promote investment in energy infrastructure and clean technologies as reflected in the renewable energy auctions promoted in Spain and Portugal.

Goal 13: Take urgent action to combat climate change and its impacts.

Figure x: Goal 13: Climate action. Source: UN

In 2019, emissions of carbon dioxide and other greenhouse gases reached an historical maximum, and it was the second warmest year ever. Climate change is becoming increasingly noticeable, affecting every country on every continent.

To curb this global problem, in 2015, the Paris Agreement was adopted as an international treaty concerning climate change and its effects. One of the measures included in this agreement is the approach of a series of policies of each EU member country to reduce the number of emissions and improve the climate situation. To this purpose, each country has elaborated a National Energy and Climate Plan in which it sets out the procedures to be applied during the 2021-2030 horizon.

This objective also aims to improve education, awareness and adaptation of the population and institutions with respect to climate change.

Goal 17: Revitalise the Global Partnership for Sustainable Development.

Figure x: Goal 13: Alliances for the objectives. Source: UN

The global and transversal nature of the fight against climate change requires coordination and alliances between different countries. One example is the Paris Agreement mentioned in the previous objective. Furthermore, it is necessary to develop cooperation mechanisms that make it possible to meet the objectives in the field of energy and climate. In addition, coordination between the public and private sectors at local, regional, state, and international levels is important.