National Energy and Climate Plan 2030: modelling the Iberian power system under the New European Policy Framework

Federico Barbieri

Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

Supervisors: Prof. Carlos Augusto Santos Silva

Dr. Diana Pereira Neves

Examination Committee

Chairperson: Prof. Duarte de Mesquita e Sousa

Supervisor: Dr. Diana Pereira Neves

Member of the Committee: Prof. Tania Alexandra Dos Santos Costa e Sousa

November 2019

Abstract

With the Clean Energy Package, the European Union has agreed on a comprehensive update of its energy policy framework: the governance mechanism calls on each European Member State to submit by December 2019 its National Energy and Climate Plan (NECP), a report containing the overview of the current energy system and setting out national targets covering ten-year periods (2021-2030). If on one side the European Commission aims at ensuring the achievement of the Energy Union 2030 objectives through constant monitoring and collective action, on the other side inconsistencies may arise when comparing the NECPs of neighbouring countries. Hence, this thesis' goal is to review and analyse the Spanish and Portuguese NECPs, focusing on targets, investments and planned installation within the electricity sector. Utilising the EnergyPLAN tool, the power systems of the two Iberian countries were modelled under different conditions: Baseline and Target Scenarios, interconnected and island mode, individually and aggregated. Considering the energy systems referred in the NECPs, it was found that the dispatch of all the electricity coming from variable renewable energy sources (RES) will not be possible, even with the overexploitation of interconnection lines and pumped hydro energy storage, leading inevitably to the curtailment of electricity excess. Therefore, additional installation of RES will not necessarily lead to a proportional growth of the RES share. Developing compatible policy framework for energy systems with high renewables penetration, investments in storage facilities and the cooperation between EU Member States will be of crucial importance to advance towards 100% renewable electricity systems.

Keywords: Renewable Energy, Energy modelling, Clean energy package, National Energy and Climate Plan

Resumo

No "Pacote Energia Clima 2030", a União Europeia concordou com uma atualização do quadro de política energética: de acordo com o novo regulamento de Governo da União da Energia, cada Estado-Membro Europeu deve apresentar, até dezembro de 2019, o seu Plano Nacional de Energia e Clima (NECP) e que define as metas nacionais da próxima década (2021-2030). Se, por um lado, a Comissão Europeia pretende atingir os objetivos através de monotorização constante e ação coletiva, por outro lado, podem surgir inconsistências ao comparar os NECPs de países vizinhos. O objetivo deste relatório é rever e analisar os NECPs espanhol e português, com foco nas metas, investimentos e instalação planeada no setor de eletricidade. Com a utilização do modelo EnergyPLAN, os sistemas de energia dos dois países ibéricos foi modelado respeitando diferentes condições: Básica e Cenários Alvo, interligados e em modo ilha, individualmente e agregados. Através de várias simulações, considerando os sistemas de energia previstos pelos NECPs, verificou-se que o envio de toda a eletricidade produzida de fontes variáveis de energia renovável (RES) não será possível, mesmo com a superexploração das linhas de interligação e o armazenamento de energia hidroelétrica bombeada, levando inevitavelmente ao corte do excesso de eletricidade. Por conseguinte, instalações adicionais de RES não vão necessariamente levar a um crescimento proporcional da percentagem de RES. Para caminhar na direção de "100%" de energia renovável serão necessários uma estrutura compatível para sistemas com alta penetração de renováveis, investimentos em instalações de armazenamento de energia, e cooperação entre Estados membros.

Palavras-chave: Energia Renovaveis, Modelação energética, Pacote Energia Clima, Plano Nacional Energia e Clima

Acknowledgements:

First of all, I would like to express my gratitude to Diana and all the professors who have supervised and guided me, contributing to the realization of this Master Thesis.

One thanks you goes to the InnoEnergy Lisbon office, who makes me always feel at home, and to the CommUnity, who have pushed me to aim high with determination, courage and creativity.

One thanks you goes to the SELECT family: especially to Marco and Luigi, who showed me the environomical way and to Duarte, incredible father, teacher and supervisor.

One thanks you goes to my roommates who, living and surviving with me, taught me to be a better person.

One thanks to Edoardo, dear friend, with whom I shared, and I will share memorable experiences.

One thanks to all my travel companions, who contributed to turn these two years into an unforgettable journey, and to the people that I lost on the way, but I'm sure I will find again in the future.

One thanks to Stockholm which has tempered me and to Lisbon, which has regenerated me/brought me back to life.

One thanks to Michele, flying brother with feet still on the ground, who have paved me the way and always inspired.

Finally, all my gratitude goes to my beloved parents, Nora and Luciano, which I keep in my heart and in my mind, whose love will always bridge the thousand kilometres that separate us, wherever my career will lead me in the future.

Ringraziamenti:

Vorrei esprimere la mia gratitudine a Diana ed a tutti i professori che mi hanno guidato e supervisionato, contribuendo alla realizzazione di questa Tesi Magistrale.

Un grazie all'InnoEnergy office di Lisbona, che mi ha sempre fatto sentire a casa e alla CommUnity, che mi ha insegnato a mettermi in gioco e a puntare sempre piú in alto con determinazione, coraggio e creatività.

Un grazie alla famiglia SELECT: in particolare a Luigi e Marco per avermi insegnato la filosofia environomical e a Duarte, incredibile padre, professore e supervisor.

Un grazie ai miei coinquilini e ai Bjorkies che, vivendo e sopravvivendo con me, mi hanno insegnato ad essere una persona migliore.

Un grazie ad Edoardo, amico fidato con cui ho condiviso tante esperienze e con cui le continueró a condividere.

Un grazie a Stoccolma/Bjorksatra per avermi temprato lo spirito e un grazie a Lisbona per avermi fatto rinascere.

Un grazie a tutte le persone che hanno contribuito a rendere questi due anni un'esperienza indimenticabile e a quegli amici che ho perso per strada, ma che sono sicuro ritroveró piú avanti.

Un grazie a Michele, fratello volante con i piedi per terra, per avermi spianato la strada ed inspirato.

Infine tutta la mia riconoscenza va alla mia famiglia, Nora e Luciano, che con il loro amore riescono sempre a colmare quelle migliaia di km di distanza che ci separano.

Table of Contents

Nomenclature

TECHNICAL PARAMETERS

Parameter	Description	Unit
$A_{O\&M\_tech}$	Annual fixed O&M cost per technology	M€/year
A_{tech}	Annual investment cost per technology	M€/year
C_{tech}	Installed capacity of technology specified	MW
$CEEP$	Critical Excess Electricity Production	TWh
$CEEP_{adj_{isl}}[\%]$	Critical Excess Electricity Production adjusted under island mode	-
$\delta_{demand,k}$	Normalized hourly electricity demand distribution	-
$\delta_{hydro,k}$	Normalized hourly water input distribution	-
$\delta_{RES,k}$	RES Normalized hourly distribution profile	-
$El_{CSP\_year\_avg}$	CSP average electricity output	GWh/year
El_{demand}	Total electricity demand	TWh/year
El_{hydro}	Expected electricity production from hydropower	TWh/year
El_{load_hr}	Real hourly electricity demand	MWh
El_{prod}	Total electricity production El_{prod}	TWh/year
El_{stab}	Electricity coming from synchronous generators	MWh
El_{OUT}	Electricity output	MWh
El_{RES}	Electricity production from Renewable Sources	ktoe / GWh
EEP	Excess Electricity Production	TWh
$EEP_{adj}[\%]$	Excess Electricity Production adjusted	-
$f_{c,RES}$	RES correction factor	-
f_{grid}	Minimum grid stabilisation share	%
$f_{stab,RES}$	RES stabilisation share	%

$Fuel_{IN}$	Fuel input	GJ
η_{CSP}	Concentrated solar power efficiency	%
η_{hydro}	Hydropower power plant efficiency	%
η_{PHES}	Pump back efficiency	%
η_{PP}	Power plant overall efficiency	%
$H\&C_{RES}$	Heating and Cooling energy consumption from Renewable Sources	ktoe
I_{tech}	Total investment cost per technology	M€
$O\&M_{fix}$	Fixed Operation and Maintenance cost	% of inv.
$O\&M_{var}$	Variable Operation and Maintenance cost	€/MWh
RES	Share of Energy from Renewable Sources	%
S_{input}	Concentrated solar power energy input	TWh/year
$TFEC_{RES}$	Total Final Energy Consumption from Renewable Sources	ktoe
$Transport_{RES}$	Transport energy consumption from Renewable Sources	ktoe
W_{supply}	Total water supply to hydro reservoir	TWh/year
W_{supply_hr}	Hourly water supply to hydro reservoir	MWh

ACRONYMS

Parameter	Description	Unit
ACER	Agency for the Cooperation of Energy Regulators	-
CBMC	Contractual Balance Maintenance Costs	-
CEER	Council of European Energy Regulators	-
CEP	Clean Energy Package	-
CSP	Concentrated Solar Power	-
DG	Directorate General	-

EC	European Commission	-
EE	Energy Efficiency	-
EEA	European Environment Agency	-
ENTSO-E	European Network of Transmission System Operators for Electricity	-
ESP	Spain	-
ETS	Emission Trading System	-
EU	European Union	-
EU28	28 Member States of the European Union	-
GDP	Gross Domestic Product	-
GHG	Green-House Gases	-
HV	High Voltage	-
IEA	International Energy Agency	-
INECP	Plan Nacional Integrado de Energìa y Clima (Spain)	-
LULUCF	Land use, land-use change, and forestry	-
LV	Low Voltage	-
MIBEL	Mercado Ibérico de Electricidade (Iberian Electricity Market)	-
MS	Member States	-
MV	Medium Voltage	-
NDG	National Distribution Grid	-
NECP	National Energy and Climate Plan	-
NFER	Energy Not From Renewable Sources	-
NG	Natural Gas	-
NPV	Net Present Value	-
PCI	Project of Common Interest	-

PHES	Pumped Hydro Energy Storage	-
PNEC	Plano Nacional Energia e Clima (Portugal)	-
PNI	Programa Nacional de Investimentos / Portuguese National Investment Programme	-
PPA	Power Purchase Agreement	-
PRE	Produção em regime especial	-
PRO	Produção em regime ordinário	-
PT	Portugal	-
REC	Renewable Energy Communities	-
REN	Redes Energeticas Nacionais	-
RNC	Roteiro para a Neutralidade Carbónica	-
SC	Self-consumption	-
TFEC	Total Final Energy Consumption	-
TOE	Tonne of Oil Equivalent	-
TSO	Transmission System Operator	-
TYNDP	Ten Year Network Development Plan	-
UPAC	Unidade de Produção para Autoconsumo	-
UPP	Unidade de Pequena Produção	
URDP	Union Renewable Development Platform	-

List of figures

List of tables

1 Introduction

To facilitate the energy transition and to deliver on the European Union's Paris Agreement commitments for reducing greenhouse gas (GHG) emissions, the EU has agreed on a comprehensive update of its energy policy framework, based on the European Commission proposal published on 30th November 2016.

The aim of the proposal consisted of the completion of a new energy rulebook, called the Clean energy for all Europeans package (CEP), which intends not only to highlight EU leadership in tackling the global warming, but also providing a relevant contribution to the EU long-term strategy of achieving carbon neutrality by 2050. By setting a target of 32% share of renewable energy in the final energy consumption by 2030, the main objective of the European Commission is to support the energy transition while keeping the European Union as one of the leading economies in the world, decoupling GHG emissions from its economic growth (European Commission - CEP, 2019). Additionally, the European Council specified that the goals behind the CEP were creating more jobs and attracting new investments into renewable energy, reducing dependence on energy imports and increases energy security, protecting Europe's environment and reducing air pollution.

Regarding its structure, the Clean Energy Package is divided into eight different legislative acts, which entered all into force at the end of May 2019, giving to the Member States a timeframe between 1 and 2 years to transpose the new directives into their national law. Furthermore, under the new *"Governance of the Energy Union and Climate Action Rules"* regulation, which became active on 24 December 2018 (European Commission - CEP: Governance, 2018), Member States are required to disclose and communicate their long-term strategies and national targets to the European Commission by:

- Developing Integrated National Energy and Climate Plans (NECPs) that cover the five dimensions of the energy union for the period 2021 to 2030 based on a common template, respectively:
  - Energy security, solidarity and trust
  - A fully integrated internal energy market
  - Energy efficiency
  - Climate action - decarbonisation of the economy
  - Research, innovation and competitiveness
- Submitting a draft plan by 31 December 2018 and be ready to submit the final plan by 31 December 2019 to the European Commission
- Reporting on the progress they make in implementing their NECPs on biennial basis

The above-mentioned NECPs are gathered on the Commission website (European Commission - NECPs, 2019) and represent an extremely useful source of data, both for retrieving past statistical values and for obtaining information on future national strategies and planned investments.

Digitalisation, decarbonisation and decentralisation are expected to radically transform the power sector in the next decade driven by the rise of new technologies, the downward trends of renewable energy prices, the withdrawal of Feed-in-Tariff and the application of new methods to allocate new capacity, such as renewable energy auctions.

In all this uncertainty, it is fundamental to evaluate the potential consequences of policy proposals or projects implementation, by performing diverse analysis and impact assessments in order to predicting how a certain energy system will mutate throughout the years. With the growing availability of data and computational power, energy modelling is becoming a crucial tool to support the governments in their decision making and strategic choices, aiming at a clean, affordable and reliable energy system while ensuring a fair and just energy transition.

1.1 Research Hypothesis and Goals

The European Commission itself always promotes bilateral collaboration among Member States to enhance regional cooperation, facilitating market integration and cost-efficient policies and measures. However, each NECP is a national plan and its assumptions might be limited to the national boundaries, as highlighted by the European Commission Energy Policy Coordination working group, which assessed the NECPs (Pinho, 2019)[1]. In specific, looking at the renewable energy and interconnection targets within Iberian market, the ability for electricity exchange and storage must be investigated in order to confirm the coping of the Portuguese and Spanish NECPs, which if not may incur in deviations, leading to the overshooting of the above-mentioned targets (Pina, 2019).

Given the fact that the NECP is a policy tool, the achievements of the national targets will mainly depend on how each country will implement the European directives into its national law, how many investments will be allocated to facilitate the energy transition, the national strategy throughout the years and the response from the main market players.

Hence, taking into considerations the national energy mix, grid structure and constraints, the main research goals of this Master thesis are:

- Review and comparison of the National Energy and Climate Plans of Portugal and Spain, with a specific focus on the electricity sector including capacity, targets and investments;
- Model the national power system of Portugal and Spain, given the inputs from the two NECPs, individually and aggregated in the Iberia setting;
- Assess a technical analysis of the NECP proposals, evaluating the consistency and feasibility of both NECPs and focusing especially on the effect of increasing penetration of renewable energy.

1.2 Thesis Structure

The thesis is organized as follows:

- Chapter 2 provides a detailed description of the Clean Energy Package. Each directive is split into different subchapters and the articles which are likely to affect the power grid are emphasized;

[1] Paula Pinho: Head of Unit at the Directorate-General Energy in the European Commission and responsible for the overall coordination of the assessment of the national Energy and Climate Plans

- In Chapter 3, the overview of the Iberian market and power sector characteristics are presented, including generation, interconnections and electricity demand. Here, the current national regulatory framework is considered as well for both Portugal and Spain;
- Chapter 4 includes a comprehensive analysis of both NECPs, showing the key points, targets and policies of each country;
- Chapter 5 describes the methodology to respond to the research hypothesis and goals. A subchapter on energy modelling is included as well, explaining the motivation behind the choice of EnergyPLAN and how it was implemented. Then, the steps and inputs for the creation of the 2030 scenario are illustrated, showing how future predictions are implemented in the model;
- Chapter 6 contains the validation of the energy model: a technical analysis is carried out for Portugal, year 2017. The results are then compared with real values of the same year to demonstrate the consistency of the model and to identify possible deviations or errors.
- Chapter 7 shows the implementation of the technical analysis on the Iberian case study and presents the outcomes of the 2030 different scenarios: firstly, both Portugal and Spain are modelled in both interconnected and island mode. Afterwards, the two countries are aggregated and the entire Iberia Peninsula is modelled. Furthermore, a sensitivity analysis is included for Portugal, analysing the relationship between additional capacity of variable renewable energy and electricity excess production as well as the influence of hydropower on the final share of renewables;
- Chapter 8 presents the conclusions.

2 Clean Energy Package for all Europeans

The Clean Energy Package for all Europeans is the result of a long complex legislative process which started in 2016 with the initial proposal published by the European Commission and completed in June 2019, after an iterative negotiation process which involved several stakeholders and EU institutions. The new legislative package sets as objectives a binding target of 32% for renewable energy sources in the EU energy mix by 2030, a GHG reduction of -40% as compared to 2005 levels and an energy efficiency target of 32.5%[2] (European Commission - CEP, 2019), based on projections of the PRIMES model developed in 2007 by a consortium led by the National Technical University of Athens (E3MLab) for the European Commission. These projections represent a reference for the development of scenarios on alternative policy approaches or under different framework conditions (European Commission, 2008), hence all the policy scenarios are constructed with reference to this Baseline scenario to examine the achievement of energy policy targets.

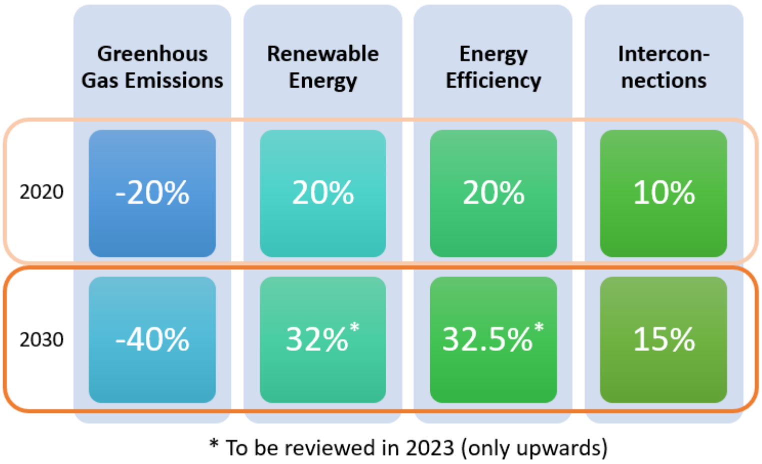


Figure 1 - Agreed headline targets: 2020 & 2030. Adapted from: (European Commission - CEP, 2019)

Table 1 presents a compilation of the main topics in each of the eight dossiers that constitutes the CEP. A more detailed description of each package is presented in the following subchapters, where articles that involves the electricity sector or will affect the power grid are detailed.

Table 1 - Directives of the Clean Energy Package. Adapted from (European Commission - CEP, 2019)

#	PACKAGE	CONTENT
1	Energy Performance in Buildings	• Path towards smarter zero-emission building by 2050 • Smart readiness indicator • E-mobility • Building renovation
2	Renewable Energy	• EU Renewable Energy target: 32% by 2030 • Reduction of air pollution • Long terms contracts and permits • Introduction of Self-consumers and Renewable Energy Communities

[2] Reduction in primary energy consumption compared to the Baseline scenario, namely projections made in years 2007 for primary energy consumption

		• Jobs & Investments • Bioenergy: new emissions regulations
3	Energy Efficiency	• EU Energy Efficiency target: 32.5% reduction by 2030 • Households, transport and industry • Energy savings
4	Governance of the Energy Union	• Mechanism for the legislative foundation from 2021 to 2030 taking into account different countries' characteristics • Commitments between the EU and its state members
5-6	Electricity Regulation & Directive	• Common rules for the internal electricity market
7	Risk Preparedness	• Tools to prevent, prepare for and manage electricity crisis situations
8	ACER	• Establishing a European Union Agency for the Cooperation of Energy Regulators

Furthermore, the EU progress on RES, EE, GHGs from 2005 towards 2020 and 2030 targets on climate and energy is shown in Figure 2.

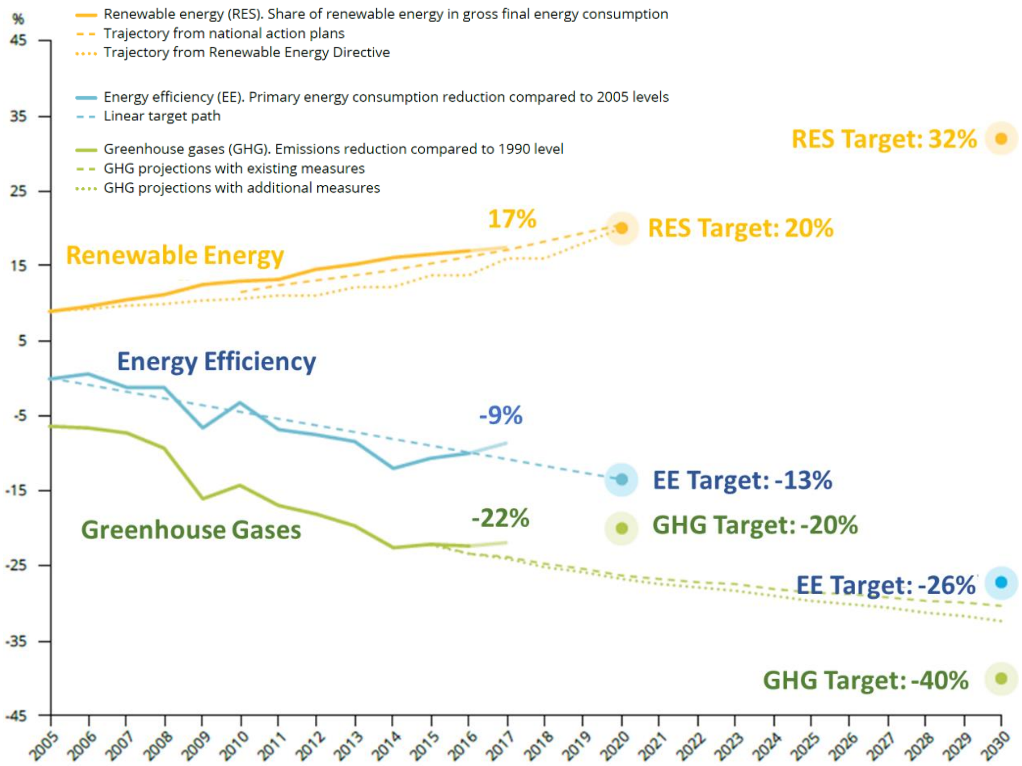


Figure 2 - EU trajectories and targets of RES, EE[3] and GHG. Source: (European Environment Agency, 2018)

[3] *EE target expressed in figure as a relative change compared with 2005 levels of primary energy consumption in the EU to show the required reduction in primary energy consumption over time

2.1 Energy Performance in Buildings

Buildings represent the largest energy consumer in Europe and are responsible for approximately 40% of the energy consumption and 36% of CO_2 emissions in the EU. Therefore, improving energy performance of EU buildings is one crucial step towards the achievement of EU energy and climate goals.

The Energy Performance in Buildings Directive (EPBD) 2018/844/EU set a more ambitious framework, replacing Directive 2010/31/EU (EPBD)[4], whose many provisions were updated. All the regulations, administrative provisions and laws required to comply with this Directive shall be brought into force by each Member State by 10 March 2020.

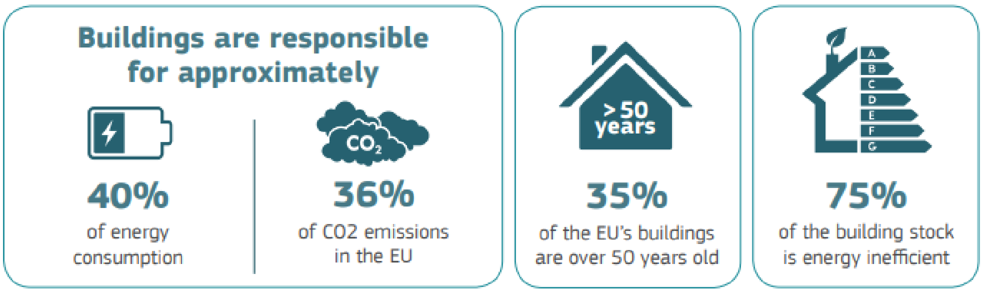


Figure 3 - Energy performance of EU buildings. Source: (European Commission - CEP: Buildings, 2019)

2.2 Renewable Energy

The Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources is the result of the recast of the previous Directive 2009/28/EC[5], which has been substantially amended several times.

Article 1 of the Renewable Energy Directive describes the subject matter and the new policy framework as follows:

"This Directive establishes a common framework for the promotion of energy from renewable sources. It sets a binding Union target for the overall share of energy from renewable sources in the Union's gross final consumption of energy in 2030. It also lays down rules on financial support for electricity from renewable sources, on self-consumption of such electricity, on the use of energy from renewable sources in the heating and cooling sector and in the transport sector, on regional cooperation between Member States, and between Member States and third countries, on guarantees of origin, on administrative procedures and on information and training. It also establishes sustainability and greenhouse gas emissions saving criteria for biofuels, bioliquids and biomass fuels."

In Figure 4, the share of energy from RES in 2017 is provided, which represented 17.5 % of energy consumed in the EU, on a path to the 2020 target of 20%. Among the EU countries in 2017, Portugal places itself on the 7th position, whilst Spain ranks 14th (both represented in red boxes in the graph below).

[4] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)
[5] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (OJ L 140, 5.6.2009, p. 16).

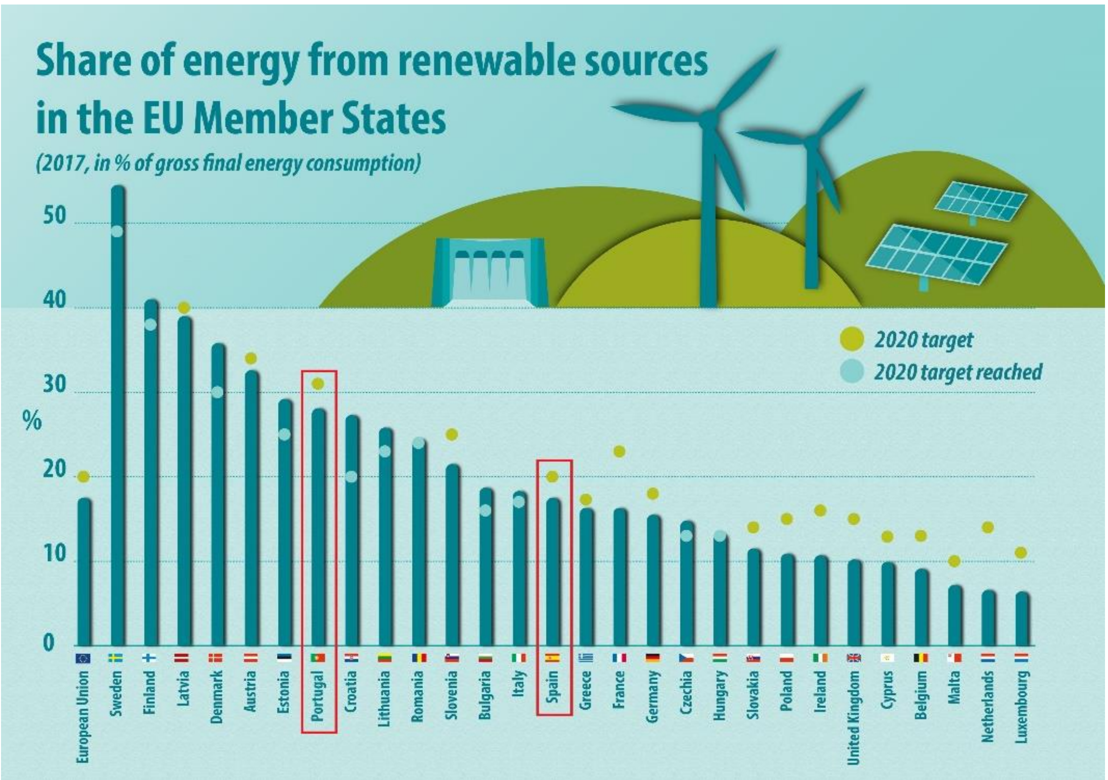


Figure 4 - Share of energy from renewable sources in the EU Members States. Source: (Eurostat - Renewables, 2019)

The previous RES Directive (Directive 2009/28/EC as amended by Directive (EU) 2015/1513) set binding national targets for the share of RES in the final energy consumption of each EU Member State. These targets ranged from 10 % (Malta) to 49 % (Sweden), contributing all together to an EU share of at least 20% RES in final energy consumption by 2020 (European Parliament - Renewable Energy, 2019). According to European Environment Agency (EEA), 25 of the 28 countries are expected to achieve their national target share the existing measures, whilst more efforts are required by Luxembourg, France and the Netherlands (European Environment Agency, 2018).

The above-mentioned targets are to be revised in 2023 and a timeline of the main points of the legislative process has been included in the figure below, created taking information from the Legislation Briefing document on Renewable Energy from the European Parliament.

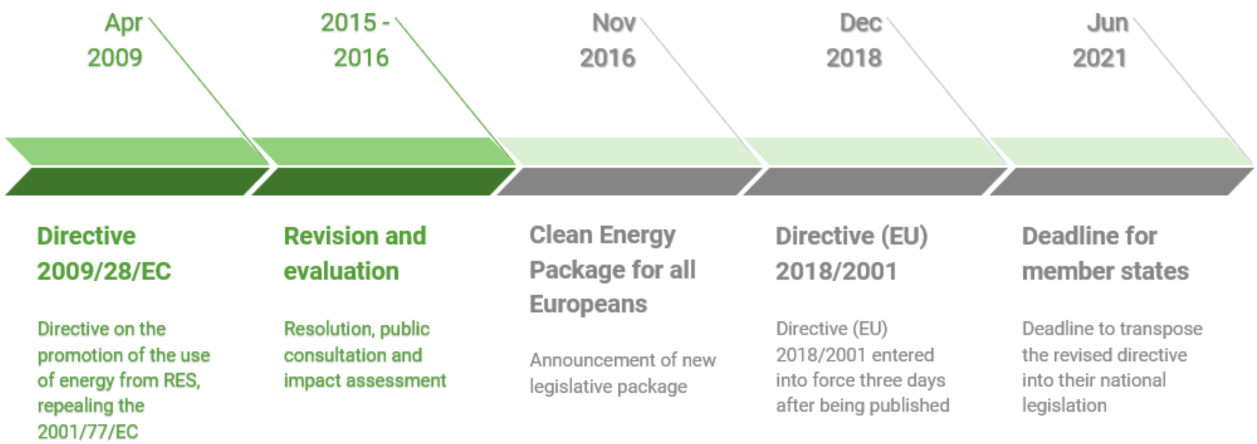


Figure 5 - Timeline of Renewable Energy Directive. Adapted from: (European Parliament - Renewable Energy, 2019)

In the following subchapters, relevant articles will be described and grouped under categories for the sake of Directive's comprehension.

2.2.1 General provision

Whereas *Article 1* introduces the subject matter and *Article 2* provides relevant definitions for the purposes of the Directive, *Article 3* specifies the 32% binding overall Union gross final energy consumption target for 2030, which must be meet collectively by the Member States, which will set national contributions. Moreover, it is specified that from 2021 Member States are not allowed to have a gross final energy consumption lower than their 2020 RES share, which will represent their baseline.

Within the same article, the 15% electricity interconnection target is included, aiming to facilitate the integration of RES into the energy system and increasing the technically feasible and economically affordable level of renewable energy across the Member States and even third countries. The interconnection level is defined as shown in the equation below, whose calculation methodology is still under discussion at the European Commission:

$$Interconnection_{MS}\ [\%] = \frac{Import\ capacity_{MS} * 0.8}{Installed\ Generation\ capacity_{MS}} \quad (1)$$

The EC did not specify any target for the share of renewables in the electricity mix , which is set by each Member State according to the state-of-the-art of their own national grid and future potential, as it will be investigated in Chapter 4.

2.2.2 Support schemes for RES and regulation

By applying support schemes, the EC aims to provide long-term certainty for investors while ensuring the RES adoption and thus the maximisation of the integration of electricity for renewable sources in an open, transparent, competitive, non-discriminatory and cost-effective manner.

In particular, the cross cooperation shall be incentivized by opening support schemes from RES located in other Member States to an indicative share of the newly-supported capacity of at least 5% from 2023 to 2026 and at least 10% from 2027 to 2030 (*Art. 5*) and by undertaking joint projects with agreed share allocation of the electricity generation (*Art. 9*). Additionally, the EC is seeking to speed up permit granting by simplify legal procedures (set up of 'one stop shops') and limiting processing to a maximum of 3 years for new Renewable Energy Plants and 1 year for re-powering (*Art. 16*).

2.2.3 RES Measurement

Article 7 specifies what can be accounted as energy produced from renewable energy source, which is the sum of electricity from RES, energy from RES in the H&C sector and energy consumed from RES in the transport sector, as shown in the equation below. The detailed table with the distinction between what has to be accounted or excluded is shown in the Annex 10.1.

$$TFEC_{RES} = En_{RES} + H\&C_{RES} + Transport_{RES}$$

Moreover, statistical transfer between Member States will be allowed through a Union Renewable Development Platform (URDP), as stated in *Article 8*, whilst *Article 10, 11* and *12* provide more information on the calculation of RES from joint projects with EU or non-EU country.

2.3 Energy Efficiency

Being the energy saved the cheapest form of energy, energy efficiency is recognized in Directive (EU) 2018/2002 as a crucial element and a priority consideration in future investment decisions on the Union's energy infrastructure. Amending the previous Directive 2012/27/EU, a binging target of at least 32.5% energy efficiency by 2030 has been set, relative to a “business as usual” scenario defined in 2007.

The revised directive will encourage using energy more efficiently and lead to:

- Reduced energy consumption and clearer information on energy bills for households and businesses
- Less dependency on energy imports
- Incentives for producers and manufacturers to use new technologies and innovate
- More investment and job creations

At the Union level, EU28 Member States are required to put measures in place to achieve cumulative end-use energy savings for the entire obligation period 2021 to 2030, equivalent to new annual savings of at least 0.8 % of final energy consumption, which consist of average 4.4% of their annual energy consumption between now and 2030.

2.4 Governance of the Energy Union

The Regulation[6] (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action includes a new robust governance system for the Energy Union, which covers all five dimensions of the Energy Union: namely energy security, the internal market, inter-connections, and research, innovation and competitiveness. Through a consistent reporting and monitoring process, together with a transparent and coordinated planning, the Governance package set EU’s sight on ensuring that national trajectories are consistent with the Paris Agreement goals and best aligned with EU’s 2030 targets for energy and climate, taking into account the fact that different countries can contribute to the Energy Union in different ways.

As in the Directive 2018/2001 on Renewable Energy, the 1st chapter of the Governance regulation is dedicated to general provisions, respectively subject matter and scope (Art. 1) and definitions (Art. 2). Afterwards, the Integrated National Energy and Climate Plans (NECPs) are introduced for the first time in the CEP, which will be extensively described in Chapter 4 of this document.

As part of the EC monitoring in the area of renewable energy, the progress made in the share of energy from renewable sources in the Union's gross final consumption shall be assessed on the basis of an indicative Union trajectory. Reference points of at least 18%, 43% and 65% of the total increase in the share of RES should be reached respectively in 2022, 2025 and 2027. In the event of a delivery gap, the Member States will be required to implement additional measures within 1 year or explain how to close that gap.

---

[6] As “Regulation” package, it has binding legal force throughout every Member State and enter into force on a set date in all the Member States. Thus , it differs from a Directive, which lays down certain results that must be achieved but each Member State is free to decide how to transpose directives into national laws

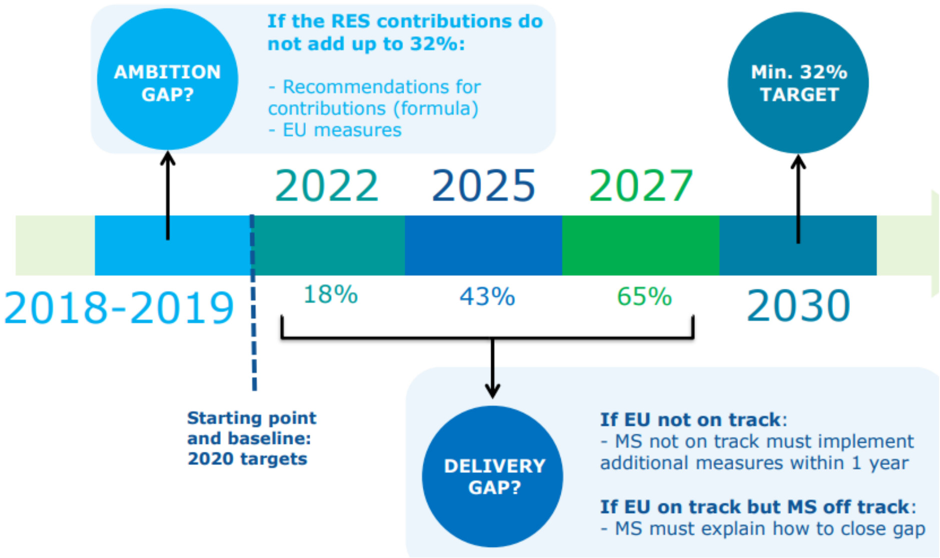


Figure 6 – Timeline of the Governance system. Source: (EUFORES, 2019)

2.5 Electricity Market Design

The EU has recently adopted a number of new laws that will make the electricity market fit for the challenges of the clean energy transition, seeking to establish a modern design for the EU electricity market – better connected, better protected against black-outs, better able to integrate renewable energy, more market-based, more flexible and more consumer-oriented.

Adopted on May 22nd 2019, the electricity market design elements consist of four dossiers:

a. New electricity regulation - Regulation (EU) 2019/943
b. Amending electricity directive - Directive (EU) 2019/944
c. Risk preparedness - Regulation (EU) 2019/941
d. Regulation outlining a stronger role for the Agency for the Cooperation of Energy Regulators (ACER) - Regulation (EU) 2019/94

3 Overview of Iberian Energy Sector

The energy balance flow diagram in the next page (Figure 8) displays the current state of the Iberian energy system, compiling the contributions and interrelations of various energy commodities (fuels, heat and power) in the different sectors of the economy, throughout the entire process (supply, transformation and consumption). Information such as fuel breakdown, import/export ratio, the efficiencies, transformation and transmission losses can be obtained by consulting this diagram.

With 162'547 ktoe (thousands tonne of oil equivalent) of energy imports, the Iberian Peninsula is a net importer, mainly of oil and petroleum products, gas and solid fuels, which all together accounts for approximately three times the total exports. Transformation losses (33'532 ktoe) represents 20.7% of the transformation inputs, losses that occur prevalently within the electricity sector: with an energy input of 54'094 ktoe, the electricity only output results equal to 25'097 ktoe, resulting in a transformation efficiency of only 46.4%. Fossil fuels still dominate the final energy consumption: Spain is a more carbon intensive country relying more on oil (48.9%) and natural gas - NG (17%) compared to Portugal, which completes its share with 46.2% of oil and 11.4% of NG. Portugal leads on Spain in the renewables and biofuels (respectively 14.1% for the former and 7.6% for the latter), while electricity on Iberia accounted cumulatively for a share of 25.5% in the final energy consumption of 2017, which is higher than the European average (around 20%). Figure 7 displays the final energy consumption for Iberia, and Spain and Portugal individually (in Mtoe) (European Commission - Energy Datasheet, 2019)[7].

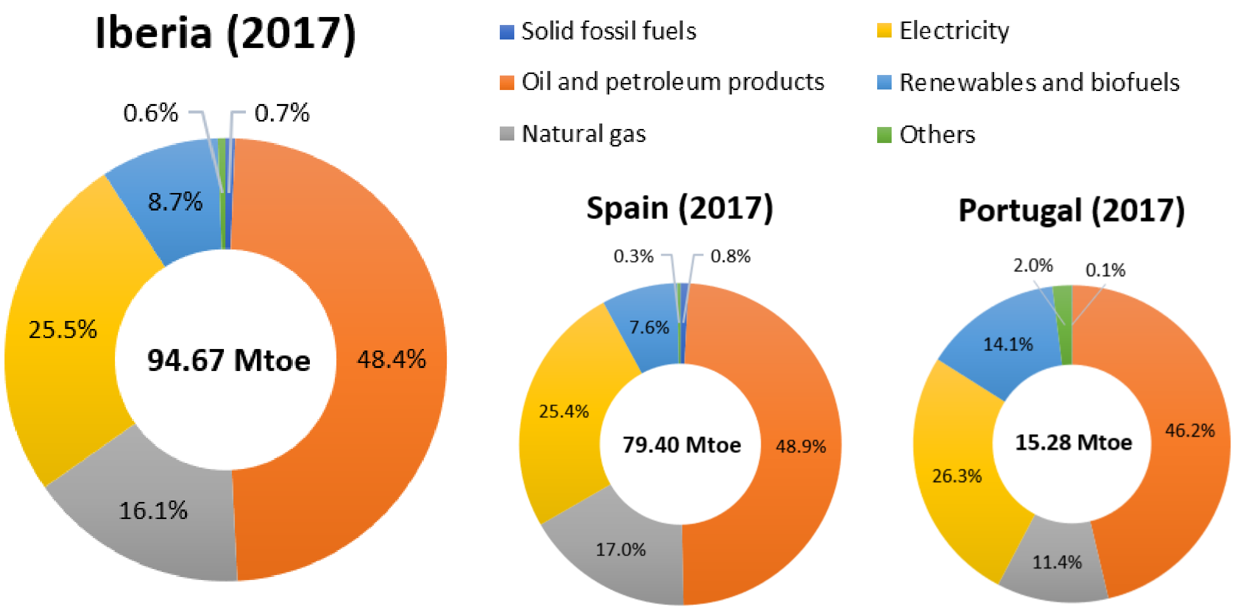


Figure 7 - Iberian Peninsula Final Energy Consumption (2017). Adapted from: (European Commission - Energy Datasheet, 2019)

[7] For the sake and consistency of comparison, the data for final energy consumption were taken from the EU28 Energy Datasheet provided by DG ENER whose percentages, due to different methodology and structure of energy balances, might slightly differ from the national energy regulator.

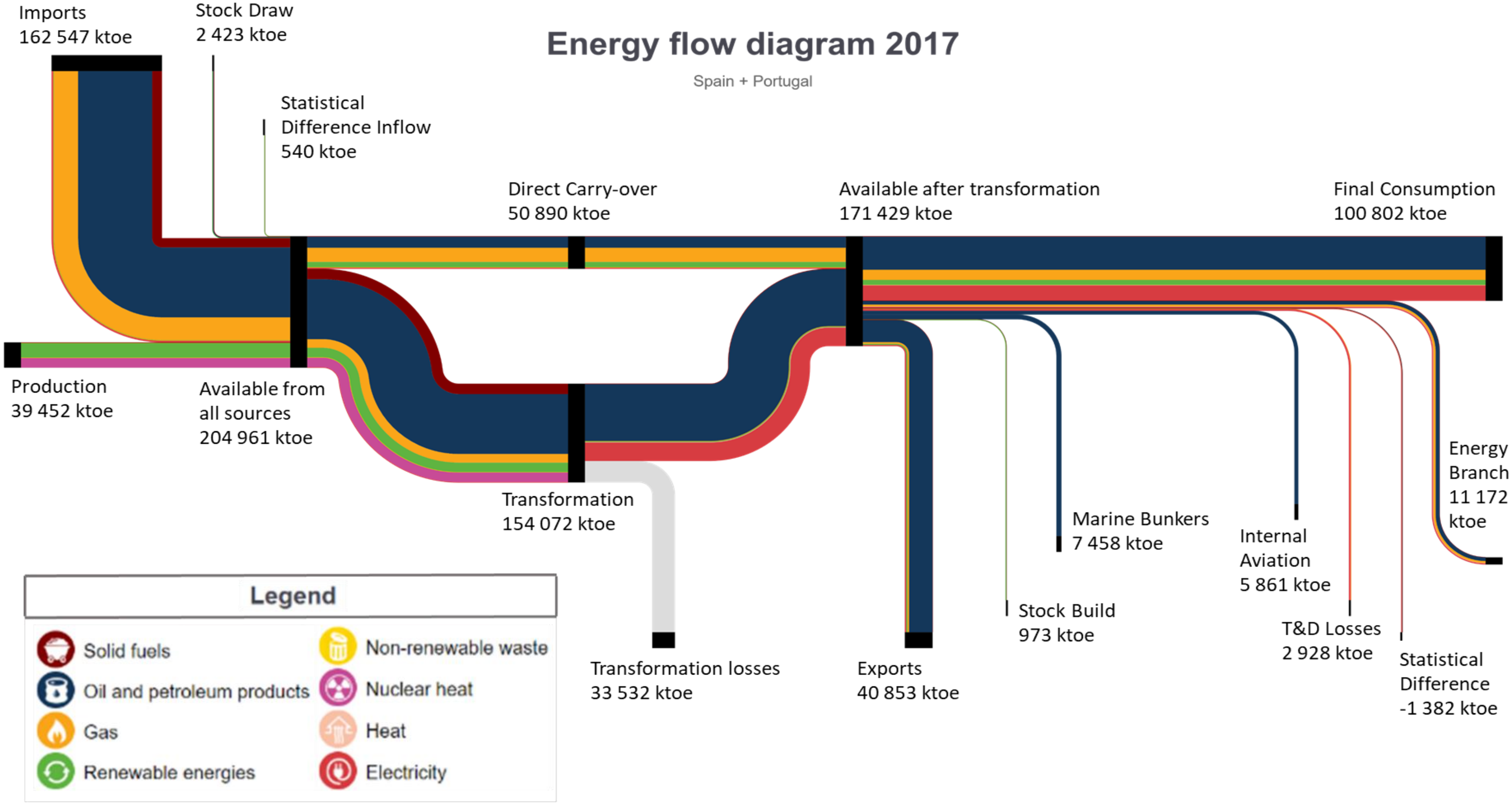


Figure 8 – Iberian Peninsula Energy Balance Flow Diagram 2017[8]. Source: (Eurostat - Energy Balance, 2019)

---

[8] Values mentioned in the text might differ, since the energy flow is "collapsed" and does not contain all the nodes (e.g. distinction between final energy/non-energy consumption

In 2017, the Iberia peninsula emitted 410.8 Mton of CO_2 equivalent (Land use, land-use change & forestry - LULUCF and international aviation excluded), with 102 Mton coming from the energy industries only. Developed countries such as Spain and Portugal are characterized by GHG emissions predominantly caused by fuel combustion activities, hitting around 75% of the total emissions, with the energy industries, public electricity and heat production representing alone 25% of the fuel-related emissions (APA, 2019), as Figure 9 shows.

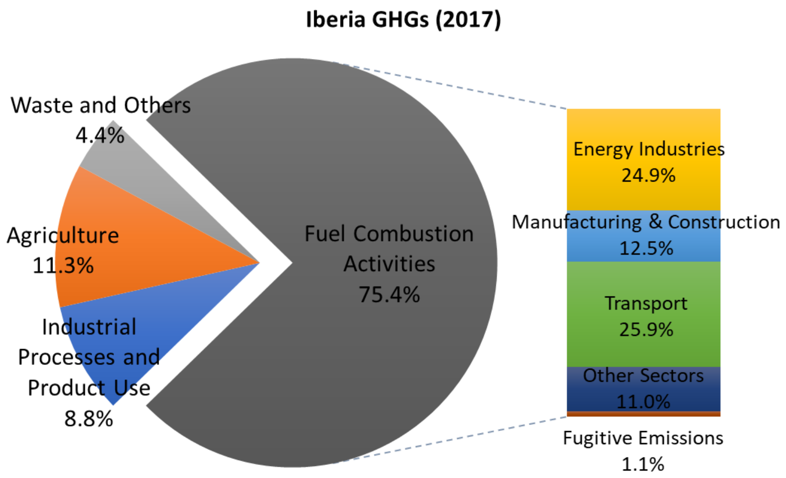


Figure 9 - Iberian Peninsula GHG Emissions by sector in 2017 (LULUCF and international aviation excluded). Adapted from: (European Commission - Energy Datasheet, 2019)

3.1 MIBEL market

Today's internal energy market for gas and electricity was established after a market liberalization process which started more than 20 years ago by means of three consecutive legislative packages, adopted in the 1990s, 2003 and 2009: Directive 96/92/EC stablished the common rules for the internal electricity market, Directive 2003/54/EC enabled new electricity suppliers to enter Member States' markets and allowed customers to choose their electricity supplier, while Directive 2009/72/EC, liberalised the market by unbundling supply, generation and networks, providing market access to third parties, and increasing the transparency of retail markets (European Parliament - Electricity Market, 2019).

One of the main purposes of the liberalization was being able to organize the provision of electricity and gas more efficiently by introducing competitive forces on wholesale and retail markets where possible and regulation where needed. Despite the fact that most Member States of the European Union (EU) are liberalizing their electricity market, with Bulgaria and Cyprus as exceptions, a European internal market for electricity has not been realized yet. Furthermore, there is still a regulated offer since the liberalization is not yet concluded.

Since the liberalization process had been carried out simultaneously across the EU, discussions between the Portuguese and Spanish authorities commenced in 1998, aiming at promoting the integration of both countries' electrical systems and reducing constrains in electricity wholesale trade between the two countries. After four particularly salient points[9],

[9] i) the signing of Protocol for the creation of an Iberian pool for electricity wholesale trade in 2001; ii) signing of the Santiago de Compostela Agreement in 2004; iii) 22nd Luso-Spanish Summit in 2006 and 2008; iv) The signing of the Agreement in Braga

this cooperation led to the successful harmonisation between the two Iberian electricity systems and the official launch of the Iberian Electricity Market on July 1st 2007 (MIBEL, 2019).

The operation of the electricity wholesale market in the current development framework of MIBEL is based on the existence of a set of contracting modalities that complement each other, which apart from the forward market, are managed by the Iberian Energy Market Operator:

- A **forward market** in which commitments are established for the future production and purchase of electricity, which is the responsibility of the Portuguese Center (OMIP). This market can carry out physical settlements (energy delivery) or financial settlements (compensation of the monetary values of the negotiation);
- An **on-demand contracting market** with a daily contracting component and an adjusted intraday component in which electricity sales and buying programs are established for the day following the negotiation;
- An **ancillary services market** which carries out balance adjustments to the production and consumption of electricity, which operates in real time;
- A **bilateral contracting market** in which the agents buy and sell electricity for the various timeframes. The supply of electricity in Portugal is yet characterized in what concerns the subjacent contracting model.

Technically speaking, the power system can be divided into 3 main components, as shown in Figure 10: generation, transmission and distribution.

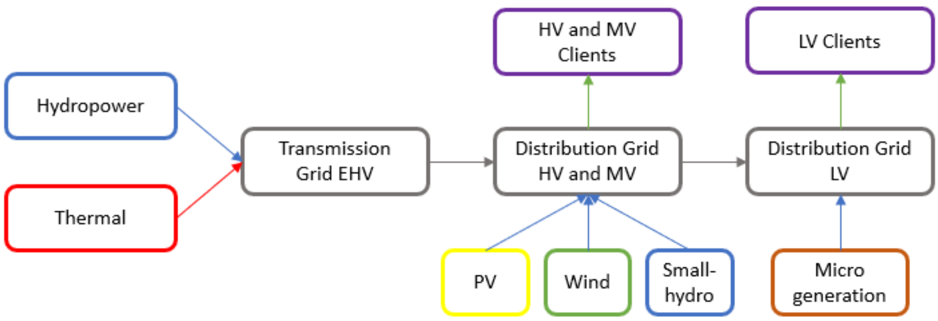


Figure 10 - Scheme of conventional power system structure. Adapted from: (Santana & Castro, 2016)

Power generation is an open to competition market driven activity and the role of the state is to ensure market equity and availability of supply. With the MIBEL implementation, all generation activities were liberalized, and plants began to offer their energy on a common, open, integrated Iberian energy platform. In particular, generation in Portugal is characterized by two legal regimes, described in Table 2.

Table 2 - Typologies of generation status. Adapted from: (Santana & Castro, 2016)

LEGAL SCHEME	WHAT	MARKET
Produção em regime ordinário (PRO)	• Traditional non-renewable sources • Large hydroelectric power stations	Open electricity market
Produção em regime especial (PRE)	• Combined Heat & Power • Small hydro • Variable renewable energy sources	Remunerated through feed-in tariffs and priority of dispatch

Produção em regime ordinário - PRO has been operating on a competition basis since 2007, when the MIBEL (Iberian Electricity Market) was implemented. Moreover, a plant remuneration was based on Power Purchase Agreements (PPA) and its operation decision was centrally managed by REN. **Produção em regime especial - PRE** is the generation activity subject to special legal schemes, which has been encouraged by EU policies in the past with the aim of fostering the development and commercialization of renewable generated electricity and the remuneration of its operators. This special generation status includes the obligation from the TSO/DSO to buy all the available electricity produced through cogeneration and endogenous resources, renewable and non-renewable sources, micro-production, mini-production and production with no network power injection (EDP Produção, 2018).

To summarize, in the current legal scheme PRE considers electricity generated from (ERSE - PRE, 2017):

- Hydro power plants until 10 MVA and under some circumstances until 30 MW;
- Other renewable variable energy resources, as wind and solar;
- Waste (urban, industrial and agriculture);
- Renewables in low tension, with installed capacity limited up to 150 kW;
- Microgeneration, with installed capacity until 5.75 kW;
- Cogeneration process.

With regards to Spain, until 2013, a special regulatory regime has been made available to co-generation facilities, mini-hydro power stations and other facilities using renewable energy sources (below 50 MW). However, the Electricity Act 24/2013[10] eliminated the former distinction between ordinary and special-regime installations, which was replaced with a new remuneration system based on the technology and capacity of the generation facilities, enabling them to compete on an equal footing with other technologies in the market. Under Act 24/2013, renewables and co-generation will participate in the wholesale market like any other technology, with renewables maintaining priority access and priority dispatch over the ordinary regime generators (conventional plants) (IEA, 2015).

3.2 Generation

Due to its renewable energy resources abundancy, the Iberian Peninsula represents a favourable location for the development of renewable energy projects, with Portugal and Spain bearing the potential to be among the leading European regions for the decarbonisation of the Union in the next decades.

3.2.1 Portugal

The total installed generation capacity in 2017 was 20.93 GW, approximately 62% of which is driven by renewable sources, registering a growth of 1.6% with respect to 2016 (European Commission - Energy Datasheet, 2019), mainly as the result of the starting of the operation of a new hydropower plant (DGEG - Installed capacity, 2019). Among the renewable energy sources, 34.5% corresponds to hydropower (7.23 GW), with an important component of pumped hydro, which represents 40% of the total hydro capacity (2.9 GW). Wind represents 24.5% of the share with 5.12 GW, while solar still lags behind with only 580 MW installed. Combustible fuels represent 38.1% (7.98 GW) of the total

[10] Electricity sector regulation (Electricity Law 24/2013)

installed capacity, with respectively 4.98 GW of Natural gas, 1.87 GW of coal and the rest in biomass and other cogeneration types (DGEG - Installed capacity, 2019). In the first decade of the 21st century, the number of electricity generators in mainland Portugal has increased significantly and it has stabilized from 2011 onwards around 20 GW.

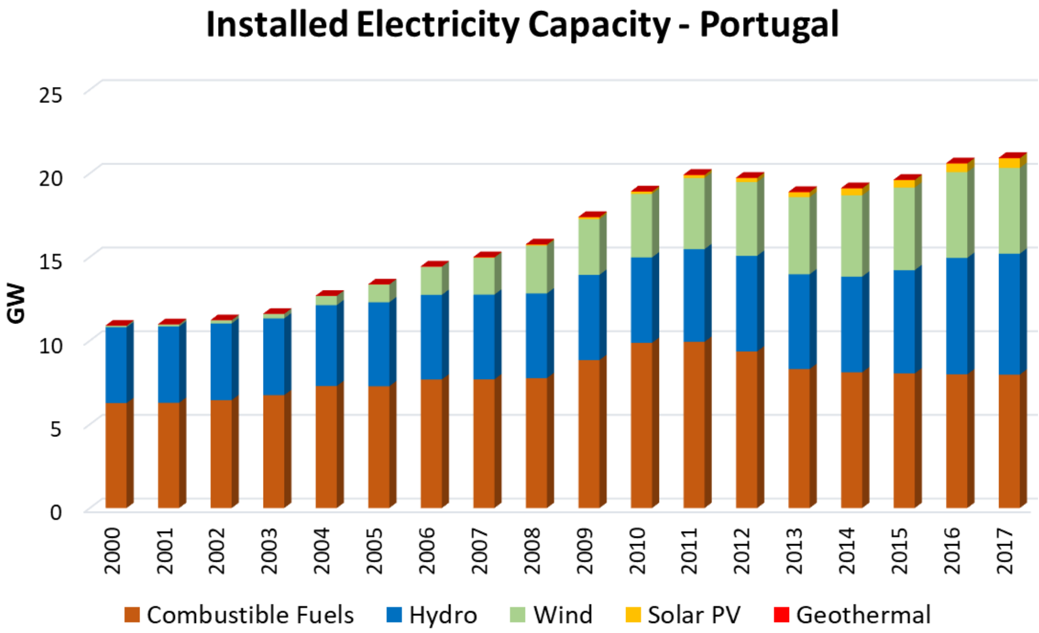


Figure 11 - Installed Electricity Capacity in Portugal. Adapted from: (European Commission - Energy Datasheet, 2019)

With regards to the electricity generated, Portugal is acknowledged as one the best performing countries in the EU28, achieving in 2017 a share of 40.6% coming from renewable energy sources. It is important to point out that 2017 was not a highly favourable hydrological year, which meant lower availability of hydro resources to produce electricity (Mendes, 2018). In fact, by analysing the statistics of the previous year, it can be noticed that the hydropower production was more than double, bringing the total renewable electricity production up to 55.5%. As depicted in Figure 12, in 2017 59.43 TWh of electricity were generated, with hydro and wind accounting together for 33% of the whole national electricity production, followed by natural gas (31.8%), coal (24.7%), biomass (5%), oil (2.2%) and solar (1.7%). Taking into account renewable electricity components only, wind contributed the most with 50.4% of the total renewable generation, followed by hydro (31.4%), biomass[11] (12.1%), solar (4.1%) and geothermal, which occurs in the Região Autónoma dos Açores only (0.9%).

[11] Solid biofuels, renewable wastes and biogases

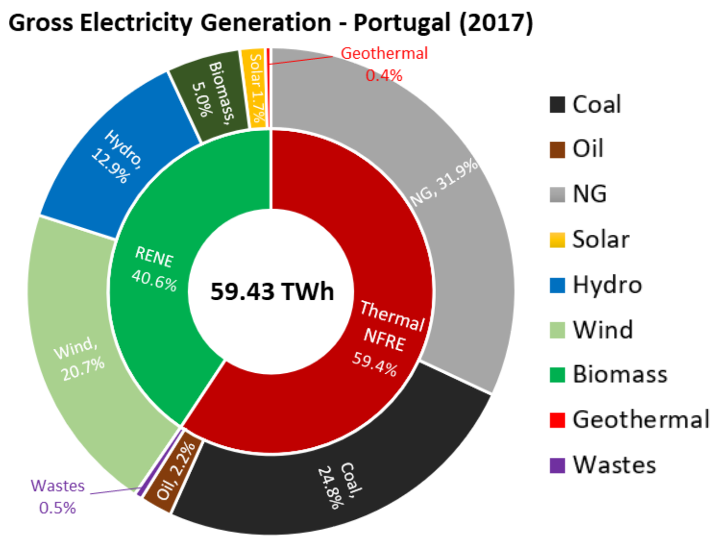


Figure 12 - Electricity generation in Portugal by fuel (2017). Adapted from: (European Commission - Energy Datasheet, 2019)

3.2.2 Spain

Spain has a quite peculiar electricity mix compared to the other EU28 members states: wind has become the predominant renewable energy source, whose installed capacity has increased exponentially in the first decade of the 21st century, overtaking hydro in 2009 and peaking at 23 GW in 2017. On the other hand, hydro consist of around 20 GW and accounts for 19% of the total installed capacity. Differently from Portugal, Spain has six operational nuclear power stations[12] with 7 GW of capacity, which remained stable since 1990. The southern position of the Iberian Peninsula guarantees a favourable solar resource, with solar PV and solar thermal comprising of respectively 4.7 GW (4.6%) and 2.3 GW (2.2%). Combustible fuels still account for a big slice of the installed capacity with 46.5 GW (44.8%), which started gradually decreasing since 2010.

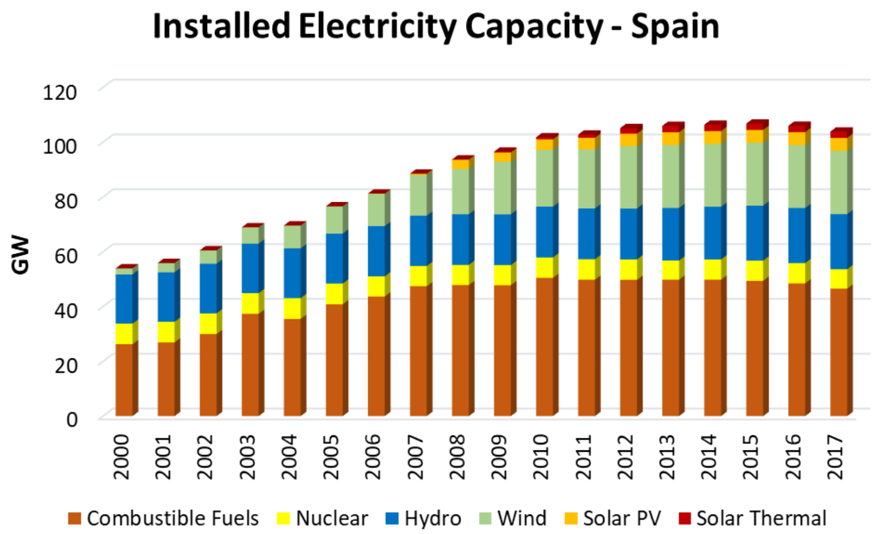


Figure 13 - Installed Electricity Capacity in Spain. Adapted from: (European Commission - Energy Datasheet, 2019)

[12] i) Almaraz I and II; ii) Ascó I and II; iii) Cofrentes; iv) Garoña; v) Vandellós II; vi) Trillo.

On the generation side, Spain has a lower penetration of renewables, reaching a renewable production share in 2017 of 32.9%[13] and 39.4% in 2016. Nuclear power plants, which constantly contributes to 21% of the gross electricity generation, allow Spain to rely less on fossil fuels[14], which in 2017 represented 45.8% of the electricity share, whilst in Portugal a peak of 58.6% was reached due to the dry year.

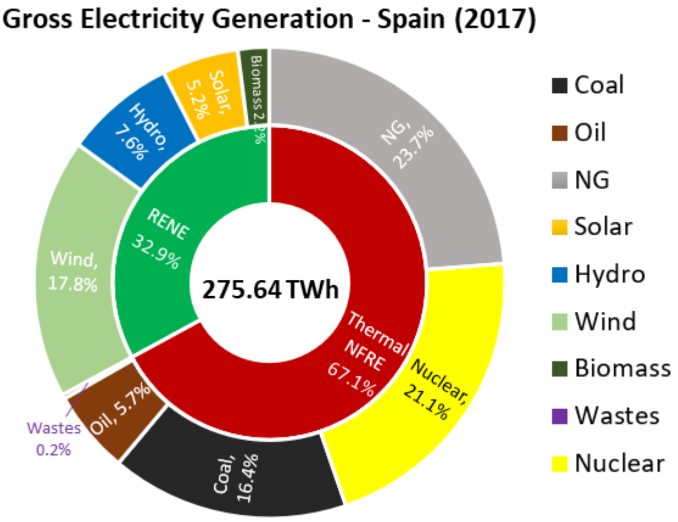


Figure 14 - Electricity Generation in Spain by fuel (2017). Adapted from: (European Commission - Energy Datasheet, 2019)

3.3 Interconnections

Located in a peripheral region of the European Union, the two Iberian countries are still below the interconnection target of 10% established by the European Commission by 2020, respectively with 6% and 9% for Spain and Portugal (ENTSO-E: Winter Outlook, 2017). After the request from the European Council in 2014 to take urgent measures to achieve the above-mentioned target, the European Commission has set out additional measures, which are expected to support more electricity interconnection projects, such as the Projects of Common Interest (PCI) (European Parliament - Interconnection, 2017).

Whilst Portugal relies only on interconnections with Spain, Spain has electricity interconnections with France, Andorra and Morocco as well. As it can be seen from Table 3, which provides details of the imports and exports between these countries and their evolution since 2010 from the Spanish perspective, Portugal resulted in being a net exporter in 2017 with 8.1 TWh, whilst Spain turned into a net importer, receiving electricity from both Portugal and particularly France, and selling it to Morocco and Andorra. Here, red values express a positive import balance, whilst negative green values a net export of electricity.

[13] All the Iberian Peninsula was affected by the draught as well as Spanish hydropower plants, which halved its hydro electricity production in 2017

[14] Solid fossil fuels, peat and products, oil shale and oil sand; oil and petroleum products; natural gas and manufactured gas

Table 3 - Physical international electricity exchange across the Spanish borders. Adapted from: (ENTSO-E: Factsheet, 2018)

YEAR	2010	2015	2017
Andorra	-264	-264	-233
France	-1531	7324	12465
Portugal	-2634	-2266	2685
Morocco	-3903	-4927	-5748
Total	-8332	-133	9169

With the interconnections planned to date, Spain will be the only country in continental Europe by 2020 with a level of interconnection of less than 10 % together with Poland, as depicted in Figure 15.

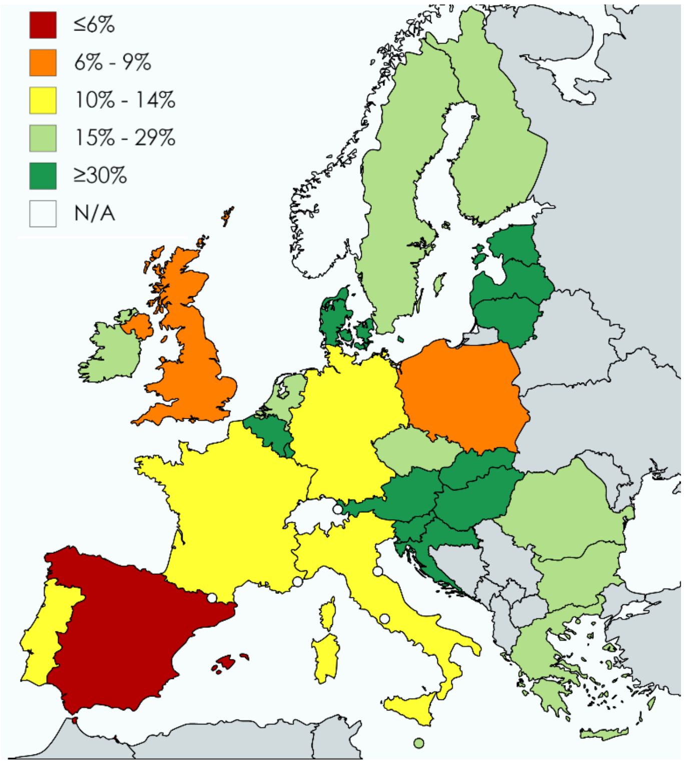


Figure 15 – Expected interconnection levels of the EU28 in 2020. Adapted from: (ENTSO-E: Winter Outlook, 2017) & (Draft PNEC, 2018) & (Draft INECP, 2019)

In order to satisfy requests from the MIBEL, the interconnection capacity for electricity between Portugal and Spain has evolved favourably in recent years. In 2017, the average commercial interconnection capacity was around 3016 MW in the Portugal-Spain direction and around 2000 MW in the Spain-Portugal direction, as can be seen in the two following graphs. The Iberian Peninsula's ambition to ensure an effective and robust connection to the European energy market is compromised due to the bottleneck that continues to exist in the interconnection between Spain and France through the Pyrenees, which ranges between 900 and 2300 MW in the France-Spain direction and between 2300 and 3400 MW in the Spain-France direction.

As far as the expected evolution of the future interconnection capacity is concerned, new projects are being discussed by the TSOs and more information are included under the "Interconnectivity" section of the NECP documents. For the Portuguese-Spanish case, the minimum indicative values are specified by Portuguese Public Consultation document and were included in Figure 16.

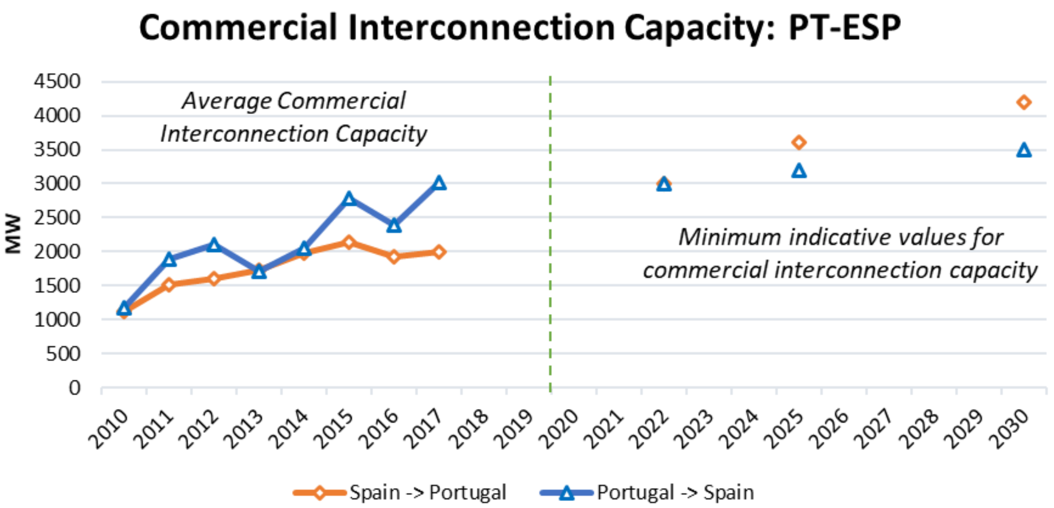


Figure 16 - Evolution of the commercial interconnection capacity between Spain and Portugal [MW]. Adapted from: (PNEC - Consulta Pública, 2019)

Additional investment projects to reinforce the interconnections with other non-Iberian countries are planned as well. For Portugal, the Morocco interconnection project is currently being studied with a forecast installed capacity of 1000 MW and it is expected to be completed by 2030; for Spain three new interconnection projects[15] with France are planned, increasing interconnection capacity up to 8000 MW (Draft INECP, 2019).

3.4 Demand, consumption and loads

Table 4 reports the peak and off-peak load for Portugal and Spain, where it is observable that peak load in Spain is around 5 times higher than in Portugal.

Table 4 - Highest and lowest hourly load values in 2017 [MW]. Adapted from: (ENTSO-E: Factsheet, 2018)

	PEAK LOAD DATE	VALUE [MW]	LOW LOAD DATE	VALUE [MW]
Spain	18.01.2017	41.02	16.04.2017	18.76
Portugal	19.01.2017	8.73	16.04.2017	3.41

As far as the evolution of the peak electricity demand is concerned, the value has been stabilizing in the latest year in both countries with a smooth decrease throughout the years, ranging between 8.1 and 8.7 GW for Portugal between 2013 and 2017. In particular, Figure 17 illustrates the yearly, summer and winter average daily load for Portugal in 2017.

[15] i) Bay of Biscay: between Aquitaine (FR) and the Basque Country (ES); ii) Aragon (ES) and Pyrénées-Atlantiques (FR); iii) Navarre (ES) and Landas (FR)

As expected, winter is characterized by higher loads compared to summer, whilst the average yearly load fits between the two curves.

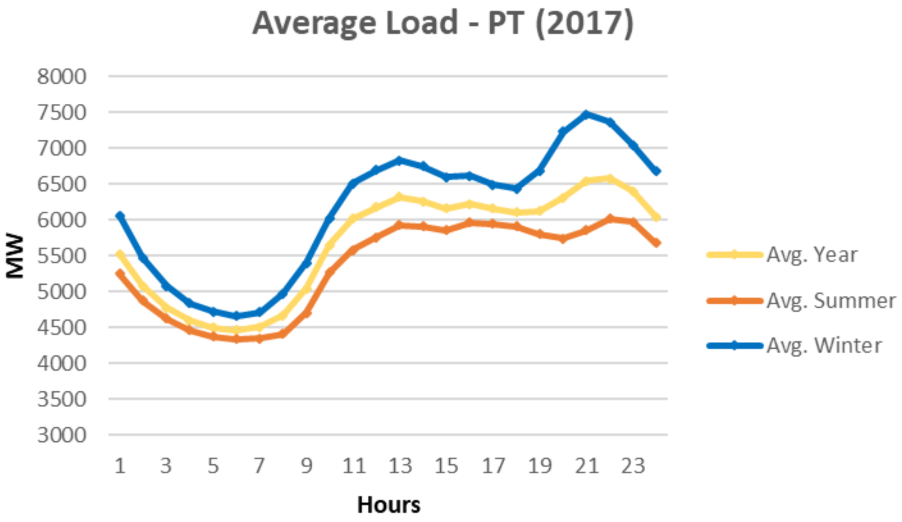


Figure 17 - Average load profile for Portugal (2017). Adapted from: (REN - Market Information, 2017)

The evolution of the electricity demand for Portugal and Spain is presented in Table 5, where it can be seen that both countries are experiencing a positive evolution in the total electricity demand from 2014 onwards: in particular, it increased by 4.2% for both Portugal and Spain over the last 4 years.

Table 5 - Evolution of the electricity demand of the Iberian Peninsula. Adapted from: (REN - Estatística Anual, 2019) & (RED - Report, 2019)

	PORTUGAL		SPAIN	
Year	**Demand [TWh]**	**Evolution**	**Demand [TWh]**	**Evolution**
2014	48.83	-0.7%	243.17	-1.1%
2015	48.96	0.3%	247.97	2.0%
2016	49.27	0.6%	249.68	0.7%
2017	49.64	0.7%	252.51	1.1%
2018	50.90	2.5%	253.50	0.4%

4 Integrated National Energy and Climate Plans

As outlined in the first chapter of the Regulation (EU) 2018/1999, the new governance regulation "sets out the necessary legislative foundation for reliable, inclusive, cost-efficient, transparent and predictable governance of the Energy Union and Climate Action (governance mechanism), which ensures the achievement of the 2030 and long-term objectives and targets of the Energy Union" (European Commission - CEP: Governance, 2018). This monitoring is essentially based on the integrated National Energy and Climate Plan (NECP): a national report containing the overview of the current energy system and policy situation of the Member State, setting out national objectives covering ten-year periods (2021-2030) and including all the different sectors. The guidelines for the drafting of the document are described comprehensively in the Regulation, whilst the transparency is ensured by public consultation, as well as integrated reporting, monitoring and data publication.

Hence, each Member State was required to submit a draft NECP report by December 2018, to be assessed by the Commission in the following months and resulted on the publication of the global assessment of the cumulative impact of these draft plans by 18 June 2019. That report included recommendations to be considered to improve the NECPs before submitting the final version by the end of 2019 (European Commission - CEP: Governance, 2018). The first deadline was not respected by most of the EU28 countries such as Spain, which submitted it two months later, although reporting a more detailed documentation compared to Portugal, which respected the deadline (European Commission - NECPs Recommendation, 2019).

Figure 18 depicts the timeline starting from the presentation of the Clean Energy Package in 2016 until the revised NECPs which will be published in 2024. The European Commission's actions are shown above the timeline and below the deadlines for the Member States can be found.

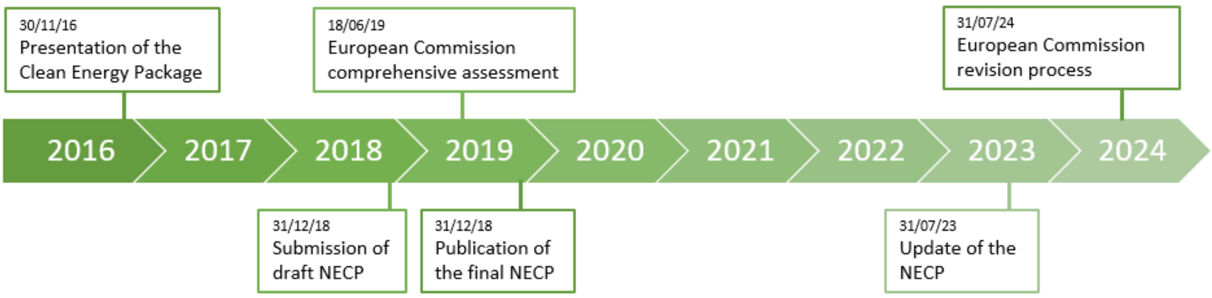


Figure 18 - Timeline of the elaboration of NECP according to the Governance regulation. Adapted from: (PNEC - Consulta Pública, 2019)

In the following subchapters, Spanish and Portuguese national targets will be detailed as result of the personal consultation of the two NECPs and recommendations from third parties, with a special focus only on the power sector, hence excluding detailing the measures on transports and industry.

4.1 Portugal: Plano Nacional Energia e Clima 2030

4.1.1 Main targets

In line with the strategic vision defined for the five dimensions of the Energy Union and Climate Action, Table 6 shows national targets and contributions for energy and climate defined for the 2030 horizon under the "Plano Nacional Energia e Clima" (PNEC).

Table 6 - Main energy and climate parameters of Portugal for the 2030 horizon. Adapted from: (Draft PNEC, 2018)

	RENEWABLES	ENERGY EFFICIENCY	GHG EMISSIONS[16]	ENERGY DEPENDENCY	RENEWABLES ELECTRICITY	RENEWABLES TRANSPORT	INTERCONNEC TIONS
2017	28.1%	23%	-22%	79.7%	54.2%	7.9%	8%
2020 Target[17]	31%	25%	-18% to -23%	74%	60%	8%	10%
2030 Target	47%	35%	-45% to -55%	65%	80%	20%	15%

As seen, Portugal aspires to reinforce the weighting of renewable energies aiming at an ambitious 47% RE target of the gross final energy consumption, equivalent to 16% points of difference between 2020 and 2030. Even with an energy efficiency target above the 32.5% EU overall objective, the EC asked Portugal to *"substantially increase ambition for final energy consumption contribution"* in its assessment, in view of the need to increase the level of efforts to reach the Union's 2030 energy efficiency target (European Commission - NECPs Recommendation, 2019). Electricity from RES target will be further discuss in the next subchapter 4.1.2.

Not owning any oil, natural gas or coal reserves, Portugal represents the 4th worst European country regarding energy dependency[18] with 79.7% of the energy imported in 2017, well above the EU average (55.1%). For the upcoming decade, by focusing on the development of endogenous renewable energy resources, the aim is for national energy dependency to continue on a downward trend, to a minimum of 65% by 2030.

4.1.2 Generation system

Table 7 illustrates the evolution's perspectives of the installed capacity divided by technology in Portugal, starting from 2015, providing different ranges of renewables capacity (such as wind, solar and hydro) for the fulfilment of the objectives established for the electricity sector.

[16] Compared to 2005 level.
[17] According to Directive 2009/28/EC
[18] Defined as net energy imports divided by gross inland energy consumption plus fuel supplied to international maritime bunkers, expressed as a percentage. A negative dependency rate indicates a net exporter of energy while a dependency rate in excess of 100 % indicates that energy products have been stocked.

Table 7 – Portuguese generation system in the H2030 Scenario [GW]. Adapted from: (PNEC - Consulta Pública, 2019)

YEAR	2015	2020	2025		2030	
SCENARIO	**Current**	**Target**	**Low-RES**	**High-RES**	**Low-RES**	**High-RES**
Hydropower	6	7	8.2		8.7	
Wind	5	5.4	6.6	7.8	8.8	9.2
of which onshore	5	5.4	6.5	7.6	8.5	8.9
of which offshore	-	-	0.1	0.2	0.3	
Solar Photovoltaic	0.4	1.9	5.3	6.4	7.8	9.3
of which centralized	0.2	1.4	4.2	5.3	6.6	8
of which decentralized	0.2	0.5	1.1	1.3	1.2	1.3
CSP	-	-	0.05	0.2	0.3	
Biomass	0.3	0.4	0.5		0.5	
Other renewables	-	-	0.01	0.1	0.1	0.3
Coal	1.8	1.8	1.8		0	
Natural Gas	4.1	3.8	3.8		2.8	
Total capacity	**17.6**	**20.3**	**26.3**	**29.7**	**28.9**	**31.1**

Between 2015 and 2030, Portugal aims at installing from 7.4 to 8.9 GW of new solar capacity, consisting of a 1950% and 2225% relative growth respectively. Wind follows with between 3.8 and 4.2 GW of new capacity, representing an increase between 76 and 84% respectively. Moreover, an increase in storage capacity is planned towards the end of the decade, with new hydro power plants (Gouvães with 880 MW of pumping capacity, Daivões and Alto Tâmega) expected to start operating by 2026 (Draft PNEC, 2018). After 2030, two coal fired plants of 1.8 GW of cumulative capacity are to be decommissioned, leaving natural gas as the only fossil source for non-renewable thermal power plants with 2.8 GW. The main reason for this termination will be the challenge for coal-fired power plants to continue to be profitable in a scenario where the price of a tonne of CO_2 will be at least €34, price which is strongly conditioned by the European response to climate change and to meet GHG mitigating targets.

With the above-mentioned capacity evolution, the renewable energy share in gross electricity generation is expected to hit 60% by 2020, 68% by 2025 and 80% by 2030, as depicted in Figure 19. The graph contains two information: the stacked line represents the gross electricity generation per year, whilst the clustered columns are the result of the normalization method, as established by the Directive 2009/28/EC[19] regarding the hydraulicity and wind resource factor.

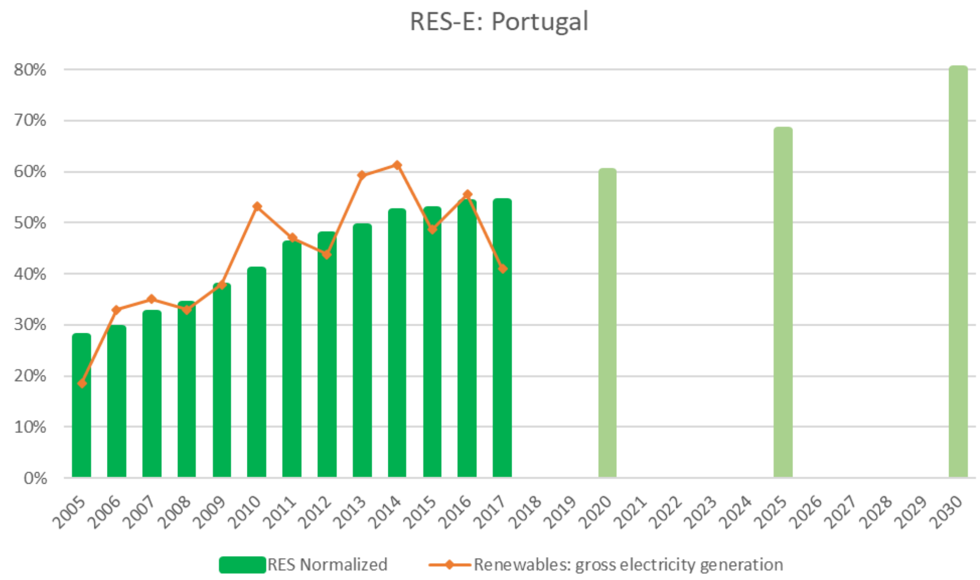


Figure 19 - Evolution of the annual generation from renewable energy in the Portuguese electricity mix in the horizon 2030. Adapted from: (Eurostat - Renewables, 2019)

Starting from 27.7% in 2005, the relative growth reached its maximum from 2010 to 2011 (+5.2%), plateauing in the subsequent period with an average of +1.6% until 2016. Assuming a linear evolution from 2017 onwards, in order to comply with the targets pre-established, shown in Table 6, renewable energy sources must grow by +1.5% points per year until 2020, +1.6% points per year until 2025 and peaking with +2.4% points per year by 2030.

Regarding the evolution of gross final energy consumption and respective energy mix, the PNEC provides indicative values of the estimated trajectories for the 2030 horizon and does not include a detailed overview of the expected electricity generation. Indicative values can be recovered from the first session of PNEC introduction, as shown in Figure 20, which occurred in January 2019.

[19] Directive 2009/28/EC establishes a standardization method within the targets in the electricity sector, that smooths the potential annual variability of hydro and wind energy, which is accentuated in years of high/low hydraulicity or high/low wind resource, respectively. Normalisation is carried out calculating generation by applying an average load factor to current capacity: for wind, the load factor is calculated as the average of the past five years (including the present one), with current capacity taken as an average of the start and end of year capacity; for hydro, the load factor is the average of the past 15 years, applied to capacity at the end of the current year.

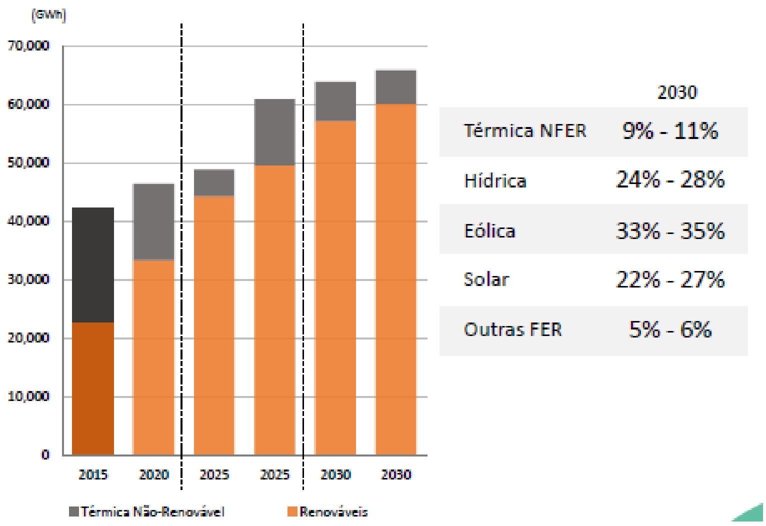


Figure 20 – Forecasted evolution of gross final electricity production for the H2030 Portuguese Scenario[20]. Source: (PNEC - Sessão de apresentação, 2019)

4.1.3 Investments

With the National Investment Programme (PNI 2030) being developed, the existing investment flows and forward investment assumptions regarding the planned policies and measures are not completely available yet at this stage. The PNI 2030 is an integral part of Portugal 2030 (PT2030) and it concretizes part of its investment strategy in infrastructures; in this context, the PNI 2030 identifies the priorities of investment on the medium and long term, in the Environment, energy and Mobility and Transport sectors.

The PNI assigns most of the total planned investment (€21.95 billion) to the transport sector (58%), which has been identified as the most urgent and demanding of financing. After transport sector, the second-largest slice is assigned energy, at €4.93 billion (23%), for eight projects, followed by Environment with €3.57 billion (16%). However, additional investment between €17.1-18.7 billion will be required in the energy sector for the achievement of the national objectives stated in the PNEC, resulting in a total investment between €22-23.6 billion by 2030, as reported in Figure 21 (PNEC - Sessão de apresentação, 2019).

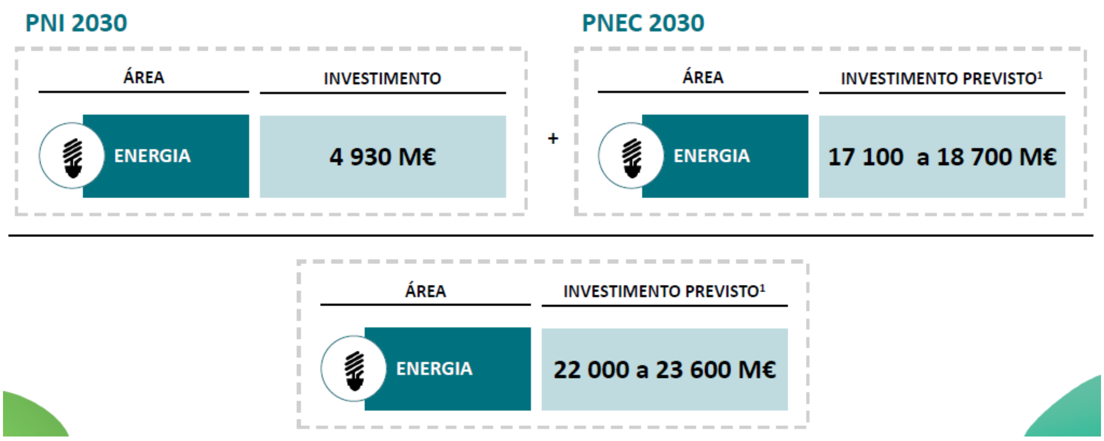


Figure 21 - Expected investment in the energy sector for Portugal. Source: (PNEC - Sessão de apresentação, 2019)

[20] Cogeneration not included. Outras FER: biomass, waves and geothermal; Thermal NFER: coal, petroleum products, natural gas.

As far as the planned installations are concerned, it is indeed relevant to report the tendering procedures through which the new large solar and wind power plants will be assigned. Auctions are indeed an innovative way for the Portuguese energy panorama to attribute investment since until now RE projects were given Feed-in tariffs. As determined by Article 4 of the Directive 2018/2001:

"Where support for electricity from renewable sources is granted by means of a tendering procedure, Member States shall, in order to ensure a high project realisation rate:

a. *establish and publish non-discriminatory and transparent criteria to qualify for the tendering procedure and set clear dates and rules for delivery of the project;*
b. *publish information about previous tendering procedures, including project realisation rates."* (European Commission, 2018)

The Portuguese government has recently published the final results and a list of all projects selected in the procurement exercise for its first competitive auction launched in June 2019. This auction allocated 1.15 GW of solar capacity, down from initial plans of around 1.4 GW, following the model of the 3 GW auction held by the Spanish government in 2017. The 1st round of auctions in question completed on August 10th 2019 resulted in the world's cheapest solar price for a competitive solar auction (Bellini, 2019), with one of the 24 licences on offer selling for 14.76 €/MWh by French IPP Akuo. The second- and third-lowest winning bids were €0.01637/kWh and €0.0171/kWh, while the highest was €0.03116/kW[21], for an average contribution agreed by developers of €21.35/MWh (Bellini, 2019).

All the winning projects will be granted 15-year PPAs and developers had the chance to present two kinds of offers:

- Fixed price below a ceiling price (45 €/MWh), which was lower than the market value
- Variable tariff, which includes a requirement to pay compensation to the electricity system.

The June 2019 auction is expected to pull in about €1.12 billion of investment, with an average investment of around €0.8 million per MW installed. At the end of May, the country's state secretary for energy João Galamba had also revealed that a second 700 MW solar auction will take place in January 2020 (Willuhn, 2019).

[21] All of these tariffs are for projects that will be awarded a fixed rate

4.2 Spain: Plan Nacional Integrado de Energìa y Clima

4.2.1 Main targets

The measures described in the "Plan Nacional Integrado de Energìa y Clima" (INECP) are supposed to lead the achievement in 2030 of the targets specified in Table 8.

Table 8 - Main energy and climate parameters of Spain for the 2030 horizon. Adapted from: (Draft INECP, 2019)

	RENEWABLES	ENERGY EFFICIENCY	GHG EMISSIONS[22]	ENERGY DEPENDENCY	RENEWABLES ELECTRICITY	RENEWABLES TRANSPORT	INTERCONNECTIONS
2017	17.5%	22.8%	-21.1%	73.9%	36.3%	5.9%	6%
2020 Target	20%	26.1%	-25%	71%	40%	10%	10%
2030 Target	42%	39.6%	-48%	59%	74%	22%	15%

Compared to Portugal, Spain starts from a lower contribution of renewable energy in 2020, with a share equivalent to the overall objective of the European Union (20%), but set his 2030 RES target at 42%, which consist of a challenging growth of +22% in the next decade. Energy efficiency is in line with the EC target, however the EC exhorted Spain to *"explore further on how the current measures would need to be further developed to realise their ambition towards achieving the expected energy savings"* (European Commission - NECPs Recommendation, 2019). Electricity from RES target will be further discuss in the next subchapter 4.2.2 as well.

Given the prevalence of fossil fuels in the national energy mix, the energy system is still characterised by high energy dependency (73.9% in 2017), holding on the positive side one of the highest levels of diversification of gas and petroleum suppliers in Europe.

4.2.2 Generation system

The Spanish NECP provides more in detail its generation system in the upcoming years, specifying all the technologies and distinguishing between the Target Scenario and the Baseline Scenario (or 2007 PRIMES Scenario), as described in Chapter 2. Table 9 presents a summary of the main technologies planned installation in the Spanish generation system:

Table 9 - Spanish generation system in the Baseline & Target Scenarios [GW]. Adapted from: (Draft INECP, 2019)

YEAR	2015	2020	2025		2030	
SCENARIO	**Current**	**Baseline**	**Baseline**	**Target**	**Baseline**	**Target**
Hydro	20.1	20.1	20.1	21.3	20.1	24.1
of which pure hydro	14.1	14.1	14.1	14.4	14.1	14.6
of which mixed pumping	2.7	2.7	2.7	2.7	2.7	2.7

[22] The GHG emission targets were computed, since the INECP does not provide the target based on 2005, but rather on 1990 levels

of which pure pumping	3.3	3.3	3.3	4.2	3.3	6.8
Wind	22.9	28.0	33.0	40.3	38.0	50.3
Solar Photovoltaic	4.9	8.4	13.4	23.4	18.4	36.9
CSP	2.3	2.3	2.3	4.8	2.3	7.3
Biomass	0.7	0.9	0.9	1.1	0.9	1.7
Other Renewables[23]	0.8	0.7	0.6	0.8	0.6	0.8
Coal	11.4	10.6	4.5	4.5	4.5	0.0-1.3
Natural Gas & Oil	35.0	34.5	33.6	33.4	32.1	32.5
Waste	0.2	0.2	0.2	0.2	0.2	0.2
Nuclear	7.4	7.4	7.4	7.4	7.4	3.2
Total	**105.6**	**113.1**	**116**	**137.1**	**124.5**	**157**

With regards to the 2030 Target Scenario and compared to 2015, the evolution of the renewables is evident. An increment of +32 GW (653% relative growth) of solar photovoltaic followed by +27 GW of wind (120% relative growth), complemented by an additional capacity of 3.5 GW pure pumped-hydro energy storage (PHES)[24], 5 GW of solar thermoelectric technologies (CSP) and 2.5 GW of batteries with a maximum of two hours' storage at full charge, whose precise composition and operation will be determined by the technological evolution and availability.

In the period 2021-2030, the planned closing of electricity generation from any coal-fired power plants will continue, phasing out a total capacity of 11 GW. However, the INECP leaves the possibility of maintaining operational part of the capacity in the case of additional investments to comply with the EU framework. Nuclear will undergo the same phasing out process, whose reactors' closure is foreseen to start in 2025 and to be completed by 2035.

With the generation asset introduced above, the result regarding renewable electricity generation is shown in Figure 22, aiming to reach 60% by 2025 and 74% by 2030. Compared to Portugal, Spain will be required to put more effort to achieve a net growth of +37% in 12 years, increasing by an ambitious 4% per year in the 2020-2025 period.

[23] Biogas, geothermal, marine energy and renewables cogeneration

[24] PHES is generally distinguished in two different types namely "pure" and "pump-back" PHS. Pure PHS (also "closed-loop" PHES) refers to stations not receiving natural inflows, located far from streams and purely serving energy storage purposes. Pump-back PHES (also "mixed" PHS) utilizes both stored water and natural inflows to produce electricity.

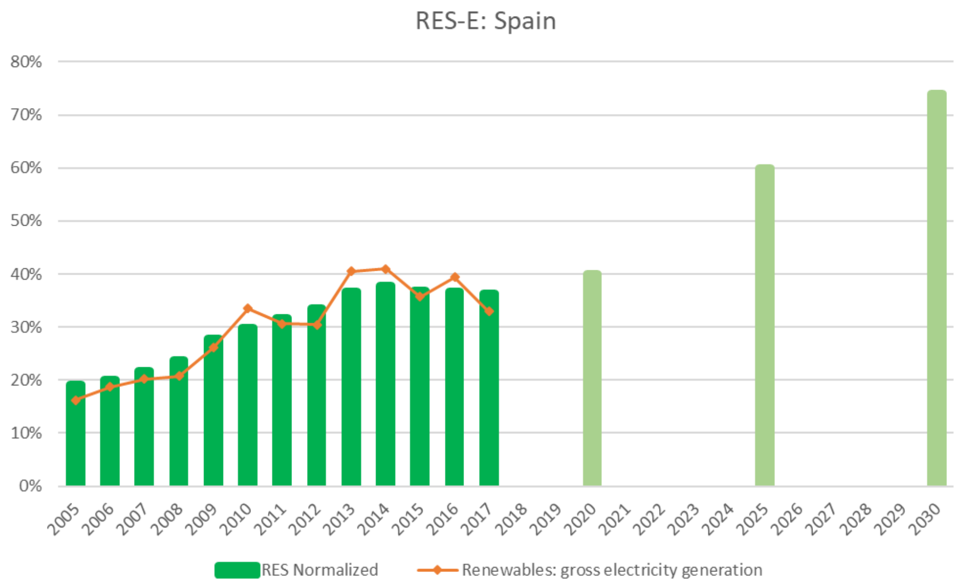


Figure 22 - Evolution of the renewable energy share in the Spanish electricity mix. Adapted from: (Eurostat - Renewables, 2019)

A detailed table with the gross electricity generation breakdown in the 2030 Baseline and Target Scenario is presented in the INECP, whose values have been summarized in Figure 23.

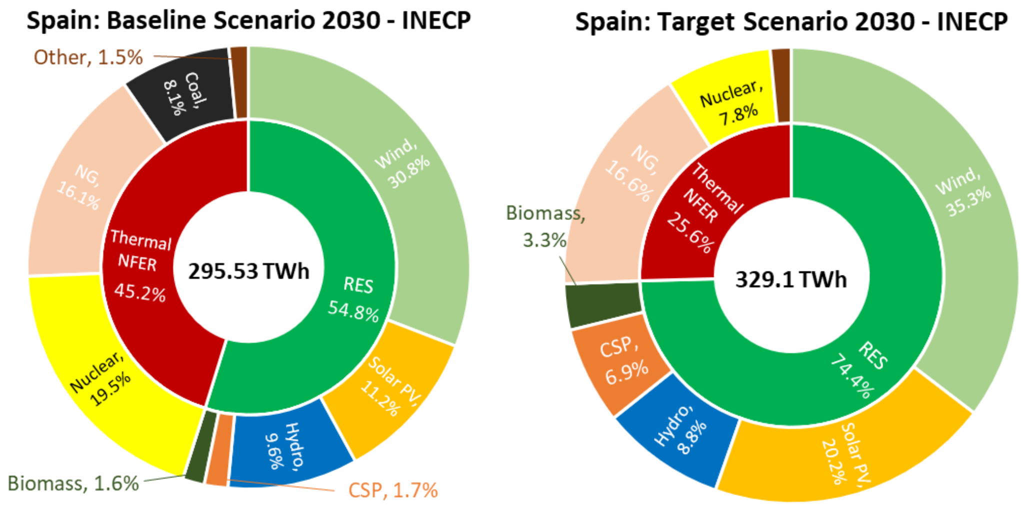


Figure 23 - Breakdown of Electricity Generation: Spain 2030 Baseline and Target Scenario. Adapted from: (Draft INECP, 2019)

4.2.3 Investments

It is estimated that the total investments needed to achieve the INECP targets will amount to € 236.12 billion between 2021 and 2030, where €195.31 billion can be considered as additional investments with respect to the baseline. These investments are grouped by measures or core topics of the energy transition, and will be distributed as follows:

- Saving and efficiency: 37 % (€86.48 bn)
- Renewables: 42 % (€101.64 bn)
- Networks and electrification: 18 % (€41.85 bn)
- Other measures: 3 % (€6.17 bn)

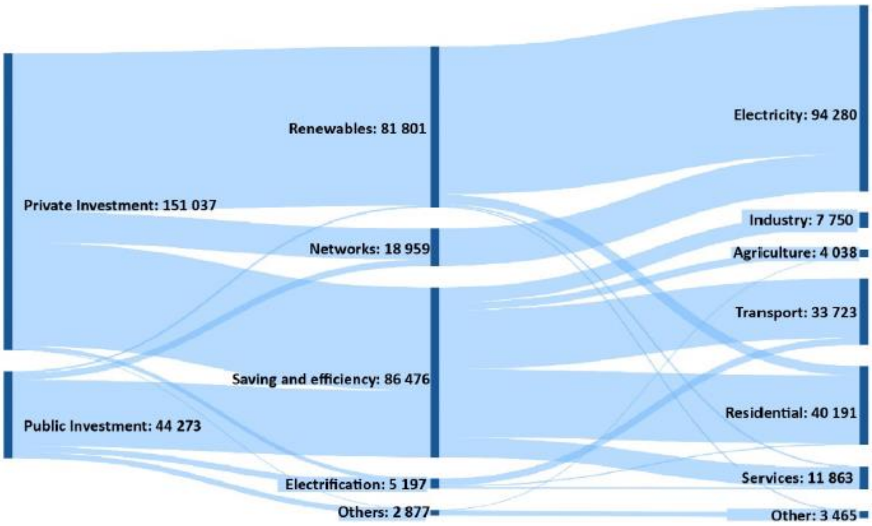


Figure 24 - Flow of additional investments from 2021-2030 to achieve the INECP targets [M€]. Source: (Basque Center for Climate Change, 2019)

According to the study carried out, the private sector will contribute to a very substantial part of the total investment (80 % of the total), mainly linked to the deployment of renewables, distribution and transmission networks, and a large part of the saving and efficiency measures. The remaining 20% will come from the public sector, contributing to energy saving and energy efficiency measures, electrification of the economy and in actions associated with promoting sustainable mobility and modal shift. As it can be seen from Figure 24, the planned investments in electricity are almost three times the investment in transport, given the higher ambition that Spain has set for his renewables electricity target, whilst Portugal has initially allocated more funding for the transport sector, as described to the PNI.

4.3 Comparison between NECPs

4.3.1 European Commission comprehensive assessment

In occasion of the European Union Sustainable Energy Week 2019, on June 2019, the European Commission has released a comprehensive assessment in which all the NECPs of the different member states are evaluated (European Commission - NECPs Recommendation, 2019). As reported in the communication, Portugal and Spain are among the Member States that have submitted the most ambitious targets for the 2030 horizon, putting forward significantly high contributions[25], as well as Lithuania, Denmark and Estonia. However, a gap for the EU28 is still present: in fact, under current draft plans, the share of renewable energy would reach between 30.4% and 31.9% only in 2030 at Union level, still slightly below the binding target identified by the European Commission of 32% (European Commission - NECPs Recommendation, 2019).

In this chapter, the main outcomes of the EC publication are analysed and summarized in Table 10, dividing the EC evaluations into different topics and sub-categories. Table 10 was created through a cross comparison the assessments

[25] In accordance with Article 31 of the Governance Regulation, the Commission's recommendations on the Member States' renewable ambitions are based on the formula set out in Annex II of the Regulation, which is based on the objective criteria listed in Article 5, whilst having due regard to relevant circumstances affecting renewable energy deployment as indicated by the Member States. The methodology followed by the Commission to assess renewable energy contributions is further detailed in Section II of the SWD (2019) 212

of the two Iberian countries and translating the evaluation into 4 parameters described in the reasoning at the bottom of the table.

Table 10 - European Commission comprehensive assessment. Adapted from: (European Commission - NECPs Recommendation, 2019)

TOPIC		DESCRIPTION		
Renewables	Targets & Ambition	Level of ambition	☑	☑
	Trajectories	Indicative trajectory reaching reference points pursuant to Article 4(a)(2) of Regulation (EU) 2018/1999 (see Chapter 2.4)	⌃	⌃
H&C	Targets & Ambition	Level of ambition	☒	☑
Transport	Targets & Measures	Level of ambition / Meeting the targets	⌃	☑
Self-consumption	Administrative Procedures	Simplification	⌃	⌃
Energy efficiency	Targets, Ambition & Measures	Ambition for final energy consumption contribution	☒	⌃
Energy security	Targets & Measures	Measures supporting the energy security objectives on diversification and reduction of energy dependency	☑	⌃
Nuclear	Phase-out	Information	☐	⌃
Market integration (electricity & gas sectors)	Objectives	Definition of forward-looking objectives and targets concerning market integration	⌃	⌃
	Measures to address tariff deficits	Address the foreseeable evolution of the tariff deficits in the electricity and gas sectors and potential impact from the measures envisaged.	☑	⌃
	Fully market-based prices	Strategy and timeline for progressing towards fully market-based prices (ESP). Measures to develop more competitive electricity and gas markets (PT)	⌃	⌃
Cooperation	Regional cooperation	Intensify the existing good regional cooperation, addressing address notably internal energy market and energy security areas	⌃	⌃

Investments & Funding	General overview		☒	☑
	Targets in R&D	Clarification of national objectives and funding targets in research, innovation and competitiveness, specifically related to the Energy Union	⌃	⌃
Energy subsidies	Plans for fossil fuels phase out	List all energy subsidies, including in particular for fossil fuels, and actions undertaken as well as plans to phase them out.	☒	☒
Air quality	Analysis of interactions between air quality and air emission policy	Info on impacts on air pollution for the various scenarios, considering synergies and trade-off effects	⌃	☑
Energy transition	Just and fair transition	More details on social, employment and skills impact of planned objectives, policies and measures.	⌃	☑
	Address Energy Poverty	Approach	⌃	☑
Publication	Draft publication	Respect of the deadline imposed by the EC for the draft	☑	☒
Reasoning	☑: adequate ambition or no comments		⌃: provide more info or put forward measures	
	☒: substantially increase ambition or info missing		☐: not mentioned or not relevant for the country	

4.3.2 Portugal and Spain NECPs Review

The two NECPs are characterized by a different structure and they implement the guidelines of the EC for the drafting of the document with different approaches. In particular, the PNEC does not provide further detailed information regarding the modelling output, except from two tables with the cost of the main technologies considered in the TIMES_PT model which contain conflicting values (Annex I of PNEC). Additionally, exports and imports are not mentioned since Portugal has been modelled as an "island". Furthermore, some values presented in the Draft NECP (e.g. expected installed capacities) are different from the *Consulta Pública*: these changes suggest that the NECP is still under revision and likely the final NECP will be characterized by other adjustments.

On the other hand, Annex D of the INECP presents the results of the generation dispatch of the 'Baseline' and 'Target' scenarios for the 2025 and 2030 time frames, together with a brief description of the methodology, the model used and the adaptation of it on the peninsular region only.

It is indeed interesting to compare not only the difference between the two scenarios, but also the expected import and export within the Iberian Peninsula: in fact, according to the TIMES-SINERGIA outputs (energy model utilized by Spain for the INECP assessment as explained in Chapter 5.2.2), the higher the penetration of renewables in the Spanish country, the higher will be the export needed to balance the internal supply and demand, whilst the import from the neighbouring countries decreases drastically, especially on the French-Spanish border[26].

With regards to the interconnection targets, as explained previously in Chapter 3.3, Portugal is expected to be characterized by 4.6 GW of interconnection capacity, which with between 28.9 and 31.1 GW of installed capacity would reach an interconnection level of respectively 14.8% and 15.9%. Differently, Spain will not achieve the 15% target with only 13.1 GW of planned export capacity over 157 GW of installed capacity, which is equivalent to 8.3% of interconnection level.

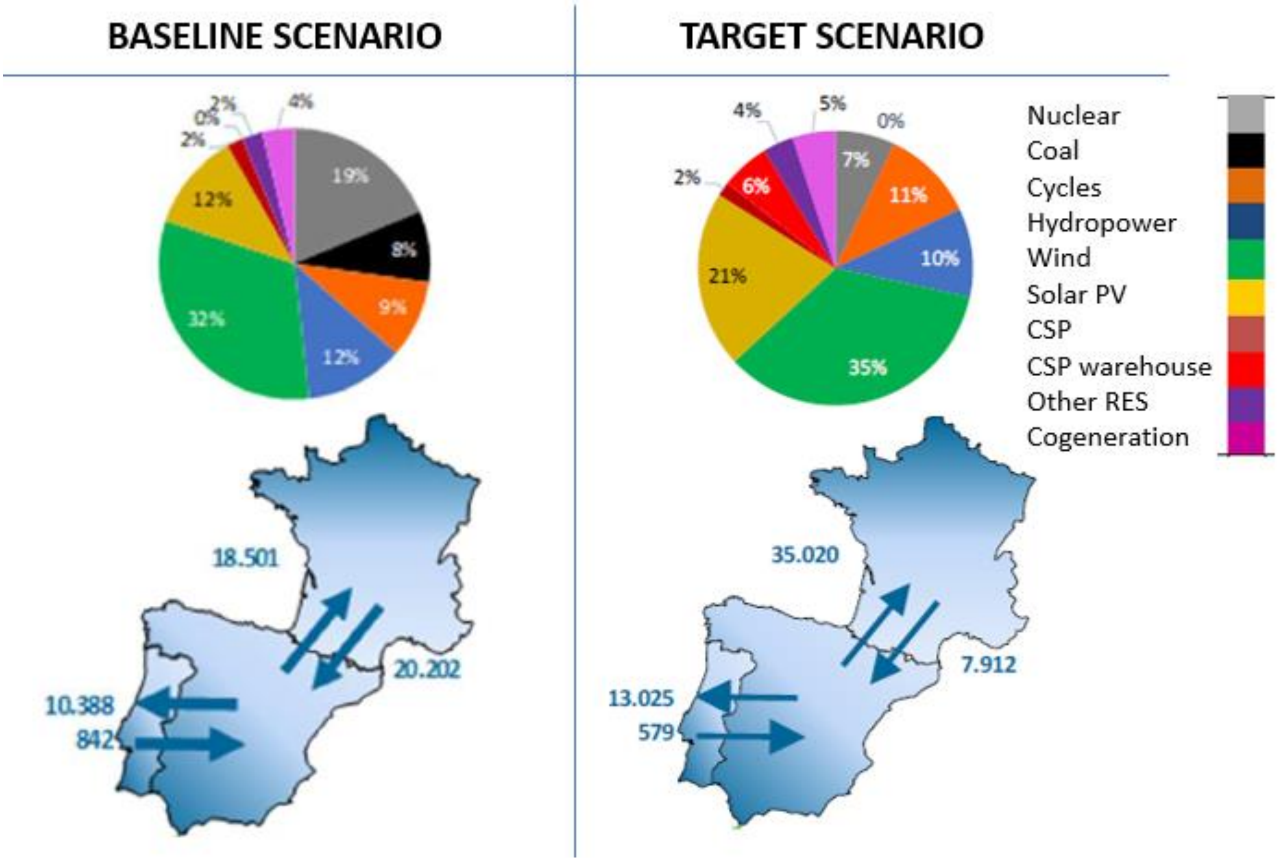


Figure 25 - Balance for yearly exchange for Baseline and Target Scenario in GWh (2030). Source: (Draft INECP, 2019)

[26] The INECP assumes no import/export with Morocco

5 Energy modelling

In this chapter the energy modelling of the Iberian electricity system is presented, as well as the methodology and the motivation behind the choice of the EnergyPLAN software. First, an assessment of the most suitable energy modelling software was made. Once decided the tool to use, data was collected and the model was validated comparing it with real data from a chosen year (2017). Subsequently, utilizing the NECPs input, the 2030 Scenarios for Portugal, Spain and Iberia electricity systems were generated. Finally, a sensitivity analysis was carried out, comparing how main parameters are affected by different Scenarios. The methodology can thus be divided into 4 different groups (literature review, validation, simulation and comparison, analysis), with the outcomes of each step explained in Figure 26.

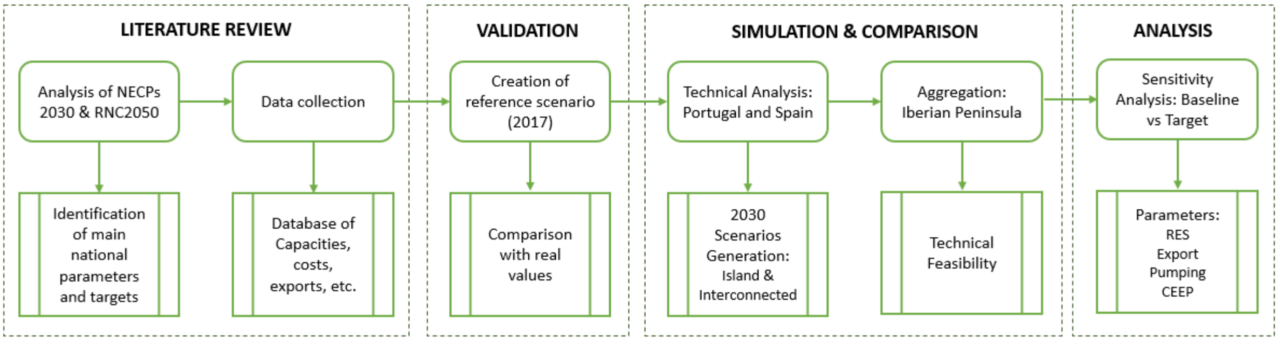


Figure 26 – Methodology

With the utilisation of an energy modelling software, different future energy scenarios will be analysed, assessing the implications of the ambitious targets stated by the two Iberian countries in their NECPs, particularly the effect of high penetration of renewables on the electricity mix.

To ensure the quality and coherency of the model, data was collected from the European Network of Transmission System Operators for Electricity (ENTSO-E), Directorate-General for Energy (DG ENER), the national energy regulators (DGEG) and TSOs (REN and RED) and processed considering the National Energy and Climate Plan (NECP) assumptions, the European Commission predictions and the RNC2050 - Roteiro para a Neutralidade Carbónica.

Differently from what has been assessed through the TIMES model (as explained in Chapter 5.2.2), the analysis will be made at hourly level (instead of 4 reference days) and it will be restricted to the power sector only, focusing on how demand and supply will be balanced in the future.

5.1 EnergyPLAN: overview and scenario definition

EnergyPLAN is deterministic input/output computer model for Energy Systems Analysis developed by the Sustainable Energy Planning Research Group of Aalborg University which optimises the operation of a given energy system in a specific year, on hourly time-steps, with inputs defined by the user. It is capable to analyse large and complex energy system at regional and national level under different technical simulation strategies and its main purpose is to analyse the energy, environmental, and economic impact of various energy strategies, aiming to assist the design of national energy planning strategies and to evaluate the consequences of different national energy systems and investments. EnergyPLAN is designed to model the low-carbon energy system of the future with large penetration of intermittent renewable energy, therefore there is a lot of emphasis on future technologies. Consequently, it can be applied to carry out three different kinds of long-term analysis as resumed in Figure 27.

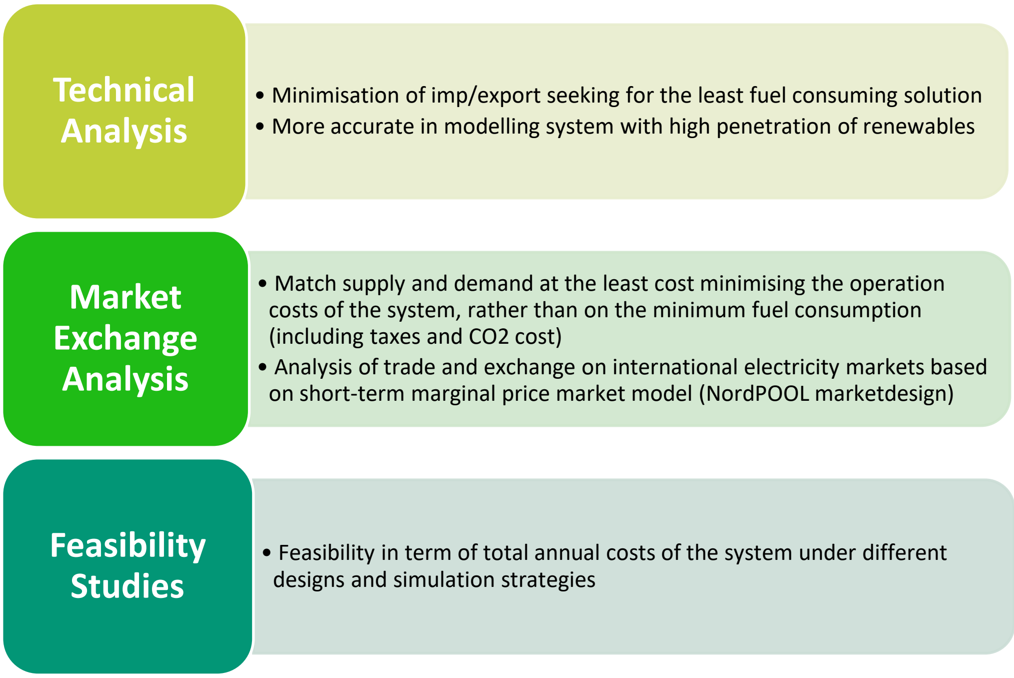


Figure 27 - Different typologies of analysis performed with EnergyPLAN. Adapted from: (Lund & Thellufsen, 2018)

Given the fact that the NECPs already provide the expected capacity installation to achieve their energy and climate objectives, it was reasonable to start from a model that requires capacity installed as input, instead of seeking for a model that optimises them.

The rationale behind the choice of this modelling tool among others available online is listed below:

- **Training:** user-friendly tool that does not require long training period and with several online training materials
- **Availability:** open-source and free to download
- **Computational effort:** requires a lower computational power compared to other energy models
- **Purpose:** EnergyPLAN was designed to simulate future energy systems with a share of renewables close to 100%, a case similar to Portugal and Spain in 2030
- **Quality:** several reports published in academic journals produced with the software and recognised by the scientific community

With EnergyPLAN, the entire energy system could be potentially modelled, including the heat sector, however only the electricity sector has been taken into consideration. Figure 28 illustrates the set of components involved in the hourly balancing of the electricity system including interactions with other parts of the whole system.

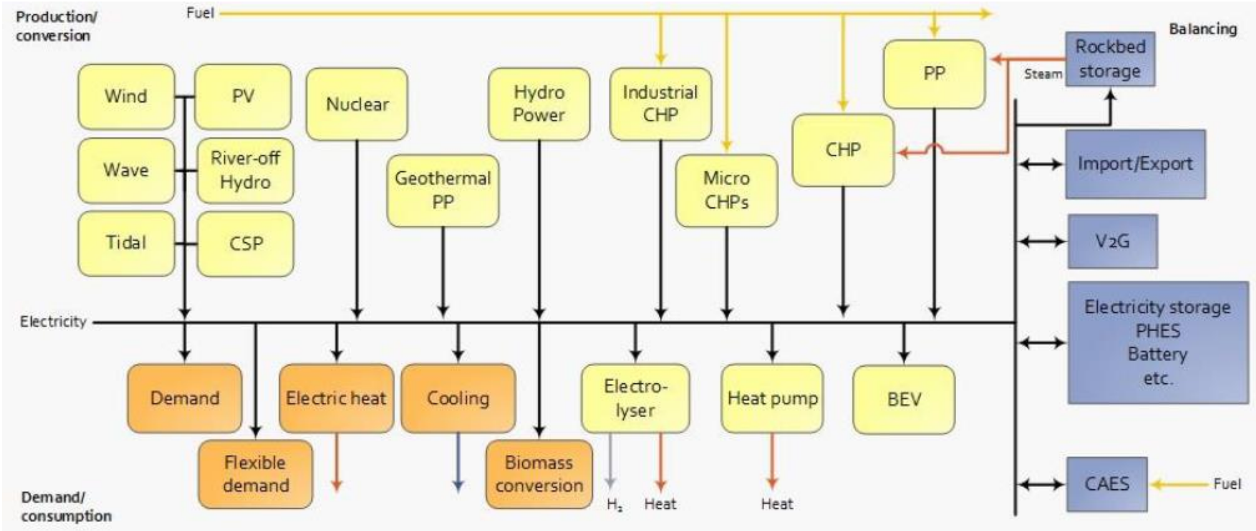


Figure 28 – Components involved in the electricity system of EnergyPLAN. Source: (Lund & Thellufsen, 2018)

Firstly, all the supply is aggregated by technology which means that if more than one power plant with the same technology exists, their capacities have to be aggregated in one big power plant in order to be modelled in EnergyPLAN. On one side this represents a big simplification, on the other side it guarantees a good trade-off between computational effort required and granularity of the system.

EnergyPLAN was not equipped with any prefilling of information regarding the Portuguese or Spanish energy systems; therefore, a collection of preliminary data was required for the functioning of the model. After training and comprehension of the model, the year 2017 was chosen for the validation being the one with the most recent and detailed data available[27]. Figure 29 provides a detailed overview of the inputs and the outputs of the EnergyPLAN model, whose relevant parameters will be further deepened in the next subchapters.

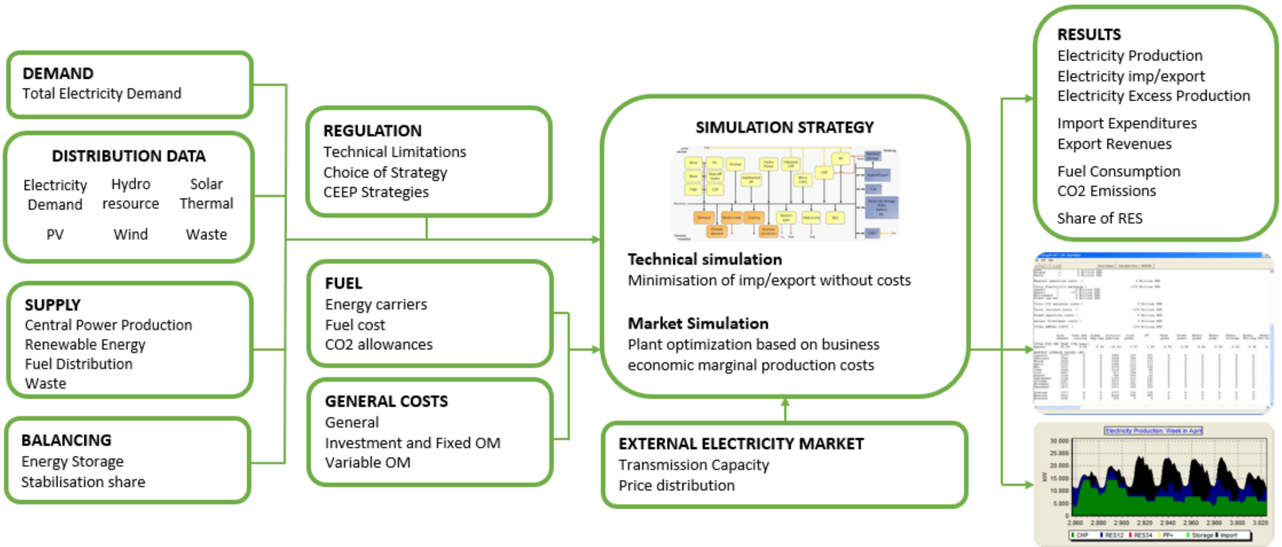


Figure 29 – EnergyPLAN: inputs and outputs. Adapted from: (Connolly, Lund, & Mathiesen, 2013)

[27] At the time of the analysis, the Eurostat database contained energy data only until year 2017

5.1.1 Demand

Electricity Demand

For the electricity demand, a distribution of 8784 values (366 days[28]) between 0 and 1 is required as input, as well as the El_{demand} (total electricity demand in TWh/year). By identifying the peak load, the hourly demand can be normalized, and the real load is computed as shown in the equation below:

$$El_{demand} = \sum_{k}^{N=8784} \delta_{demand,k} * MAX\left[El_{load\_hr}\right] \tag{2}$$

- k : hour
- $\delta_{demand,k}$: normalized hourly electricity demand
- El_{load_hr} : real hourly electricity demand [in MW]

The past load profiles of a certain country can be easily found consulting the national TSO website. Regarding the future shape of the demand profile, ENTSO-E has recently published its Ten Years Network Development Plan (TYNDP) 2018 Scenario Report which provides detailed overview of future possible European energy mixes up to 2040 (ENTSO-E: TYNDP, 2018). Three different scenarios were co-constructed with stakeholders representing the industry, NGOs, Member States and Regulators, namely:

- **Sustainable Transition (ST)**: *"Seeking a quick and economically sustainable CO2 reduction by replacing coal and lignite by gas in the power sector. Gas also displaces some oil usage in heavy transport and shipping. The electrification of heat and transport develops at a slower pace than other scenarios"* (ENTSO-E: TYNDP, 2018). In this scenario, targets are reached through national regulation, emission trading schemes and subsidies, maximising the use of existing infrastructure.
- **Distributed Generation (DG)**: *"Places prosumers at the centre. It represents a more decentralised development with focus on end user technologies. Smart technology and dual fuel appliances such as hybrid heat pumps allow consumers to switch energy depending on market conditions. Electric vehicles see their highest penetration with PV and batteries widespread in buildings. These developments lead to high levels of demand side response available"* (ENTSO-E: TYNDP, 2018). Small-scale generation and batteries engage and empower prosumers in a fuel switching society
- **External Scenario (EUCO)**: core policy scenario produced by the European Commission, which models the achievement of the 2030 climate and energy targets as agreed by the European Council in 2014, including a specified energy efficiency target (e.g. EUCO30 means 30% energy efficiency target whilst EUCO3232.5 means 32% renewable and 32.5% energy efficiency[29])

[28] In the case the period under analysis is not a leap year, the first day of the following year will be taken to complete the distribution (e.g. for the 2017 distribution, the day 1st January 2018 was included)

[29] The EUCO3232.5 report has been published in June 2019, under the same cost evolution and including additional assumptions

For the modelling of the demand profile, the **Sustainable Transition (ST) Scenario** of the two Iberian countries was used, being the most coherent and probable among the others, as well as being characterized by similar expected installed capacities by 2030 compared to the PNEC and to the INECP.

5.1.2 Supply

Central Power Production

Three types of technologies can be modelled as central power production, shown in the table below together with their efficiencies, representing the average among different plants typologies, as listed by the TYNDP:

Table 11 - Efficiencies of the main power plants. Source: (ENTSO-E: TYNDP, 2018)

	COAL	NATURAL GAS	NUCLEAR	DAMMED HYDRO
Efficiency	38%	45%	33%	90%

All the plants require as main inputs the capacity (in MW_e), which can be obtained from the national regulator or from the NECP for the 2030 Scenario. Knowing the overall efficiency of the power plant η_{PP} and the electricity generated El_{OUT} [in MWh], its fuel consumption $Fuel_{IN}$ [MWh[30]] can be determined as follows:

$$Fuel_{IN} = {El_{OUT}}/{\eta_{PP}} \quad (3)$$

To complete its operational parameters, hydropower requires:

- Storage capacity (in GWh), final and initial "State of Charge" (SOC) (in %)[31], which can be found on the TSO Real Time Information website (REN, 2019).
- C_{PHES} pump back capacity (in MW)
- η_{PHES} : pump back efficiency;
- W_{supply} : total water supply (in TWh/year), which represents the amount of water refilling the water reservoir, and its yearly distribution, which depends on the hydrological year (rainy and dry periods)

In the absence of detailed information of total water supply to all the damns in the country, the water input in the system can be computed by knowing (or assuming) the yearly electricity production and then dividing it by the average hydro efficiency rate, which is between 80% for small turbines and 95% for larger systems (Eurelectric, 2011):

$$W_{supply} = {El_{hydro}}/{\eta_{PHES}} \quad (4)$$

- El_{hydro} : expected yearly electricity production from hydropower

On the other hand, the cumulative hourly water supply W_{supply}, will be equal to the annual supply, according to the equation:

[30] In case of nuclear or fossil fuels power plant, the quantity is converted from GJ to MWh (1 GJ = 0.2778 MWh)
[31] Set automatically at 50% by the model if no input given by the user

$$W_{supply} = \sum_{k}^{N=8784} \delta_{hydro,k} * MAX[W_{supply\_hr}] \quad (5)$$

- W_{supply_hr} : hourly water supply [in GWh]
- $\delta_{hydro,k}$: normalized hourly water input, computed by analysing the average monthly rainfalls in Portugal over the past 20 years [in mm] (GEO, 2019) and in Spain, measured from the year 1930 to 1996 [in mm] (Ministerio de Medio Ambiente, 1997), as reported in Table 12.

Table 12 - Average Monthly Rainfalls in Portugal and Spain. Source: (GEO, 2019) & (Ministerio de Medio Ambiente, 1997)

	PORTUGAL		SPAIN	
Month	Avg Rainfall [mm]	Normalized	Avg Rainfall [mm]	Normalized
January	171.5	1	65.7	0.8831
February	166.8	0.9726	58.4	0.7849
March	107.6	0.6274	56.7	0.7621
April	105.7	0.6163	56.7	0.7621
May	83.5	0.4869	56.1	0.754
June	57.2	0.3335	39	0.5242
July	15.8	0.0921	19.6	0.2634
August	12	0.07	25.8	0.3468
September	51.1	0.298	46.3	0.6223
October	130.4	0.7603	68.6	0.922
November	166.3	0.9697	72.1	0.9691
December	169.8	0.9901	74.4	1

The rainfall is the most influencing parameters in the water input of a hydro power plant, thus in the absence of other accurate data on other influencing parameters, the choice of the normalization according to the rainfalls was preferred over keeping a flat and constant water input throughout the year. No other parameters are available on EnergyPLAN to control how the water stored in the reservoir is managed.

Thus, according to Table 12, the reservoirs will likely be filled until May, then discharge during the summer reaching their lowest around September and then refilled to reach the final state of charge required by the user (set as 50% if no input is given). An example of the evolution of the Portuguese and Spanish reservoirs is provided in Figure 30 and Figure

31, where the effect of the drought can be noticed with both countries reaching in 2017 the lowest level of the last 10 years (40% for Portugal and 23.8% for Spain) (REN - Estatística Anual, 2019) (RED - Report, 2019).

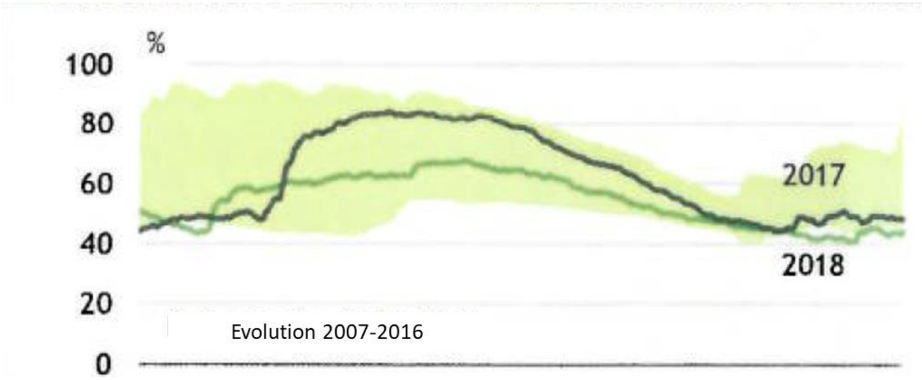


Figure 30 - Evolution of the state of charge of the hydro reservoirs throughout the years. Source: (REN - Estatística Anual, 2019)

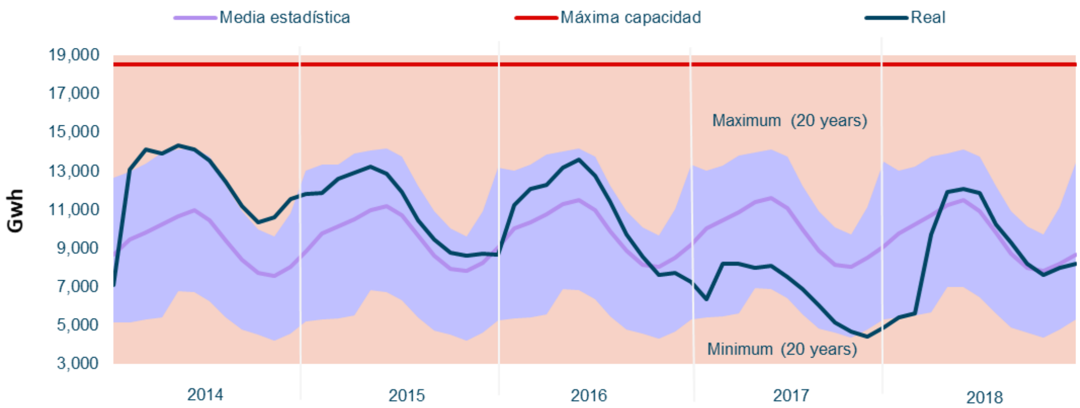


Figure 31 - Evolution of the state of charge of the hydro reservoirs throughout the years. Source: (RED - Report, 2019)

Variable Renewable Production & Concentrated Solar Power

The information required to determine the energy available from renewable energy resources in the EnergyPLAN system is listed below:

1. Type of renewable energy (technologies available for modelling are photovoltaic, onshore and offshore wind, tidal and wave power, river hydro, geothermal and biomass[32]);
2. C_{RES} : installed capacity (in MW_e);
3. $\delta_{RES,k}$: normalized hourly distribution profile;
4. $f_{stab,RES}$: share of the electricity produced by the RES that can contribute to grid stability (between 0 and 1)[33];
5. $f_{C,RES}$: correction factor, which adjusts the hourly distribution inputted for the renewable resource to take into consideration possible future improvements of the technology. In the modelling, it is used to adapt the improvements in capacity factor in the future scenario.

[32] According to DGEG data, around 57% of the electricity coming from biomass is produced through cogeneration. However, REN does not specify between biomass cogeneration and "normal" production and it aggregates both under "biomass" in its statistics
[33] At present renewable energy technologies, except for hydro plants with storage, cannot help regulating the grid and same is expected for 2030

Hence, the total yearly electricity generated El_{RES} by each technology is predetermined by the user and dependent on the MW installed, the distribution profile, the correction factor and the total energy produced, being computed as follows:

$$El_{RES} = \sum_{k}^{N=8784} C_{RES} * \delta_{RES,k} * \frac{1}{[1 - f_{C,RES} * (1 - \delta_{RES,k})]} \tag{6}$$

Concentrated Solar Power (CSP) has to be modelled given the planned new installation in Portugal for 2030 and the existing power plants in Spain. Additionally, CSP is an active component in the simulation and requires the following inputs:

- S_{input} : Annual solar input [in TWh/year];
- $\delta_{solar,k}$: solar normalized distribution profile (equivalent to the photovoltaic distribution);
- Storage capacity [in GWh];
- Storage efficiency (% of thermal losses per hour), set as 0.5%/hour (Lund & Thellufsen, 2018);
- C_{CSP} : installed power capacity [in MW_e];
- η_{CSP} : CSP power efficiency, which according to IRENA ranges between 23% and 35% for tower configuration (IRENA - CSP, 2012), hence an efficiency of 30% will be used for this case study;
- Stabilisation share: CSP is assumed to provide ancillary services, hence the stabilisation share is set to 1, which means that CSP output contributes to the grid stabilisation share, as explained in Chapter 5.1.3.

CSP has been modelled by consulting the data from the National Renewable Energy Laboratory (NREL), which together with SolarPACES has compiled data on concentrating solar power (CSP) projects around the world, including Spain. It can be noticed that each Spanish CSP, independently from the technology, have a maximum capacity of 50 MW, a yearly field electricity generation El_{CSP_year} between 100 and 180 GWh/year and 7.5 hours of storage capacity, which is equivalent to 375 MWh (NREL, 2019). Hence, the annual solar input can be obtained through reverse engineering as explained in the equation below:

$$CSP_{input} = \frac{{C_{CSP}}/{50\ MW} * El_{CSP\_year\_avg}}{\eta_{CSP}} \tag{7}$$

- $El_{CSP\_year\_avg}$: average yearly field electricity generation for a 50 MW concentrate solar power plant on the Spanish soil, equal to approximately 150 GWh/year

5.1.3 Balancing and Storage

<u>Balancing</u>

The model conducts an hourly calculation and assumes that all production units can change production from one hour to another. However, given the fact that large power plants have difficulties in going below a certain technical minimum (except for maintenance purposes), in the balancing section a minimum production can be specified for CHP and Central Power Plants. Still, no constraints will be set to power plants to not influence their operation during the calculation.

Furthermore, power plants usually provide ancillary services to ensure that the grid is maintained at a certain frequency and voltage. In the model, the minimum grid stabilisation share f_{grid} can be specified (between 0% and 100%): with the current grid infrastructure and Business as Usual (BAU) Scenario, a minimum of 50% is suggested, whilst for future scenarios, the literature recommends that 30% of the total electricity production must come from grid-stabilising units[34] (Lund & Thellufsen, 2018).

Hence, depending on the stabilisation share input, during the optimization the model forces the energy system to stay above the specified value. In the case this requirement cannot be met, the "Grid Stabilisation Problem" warning message is given.

Storage

In the electricity storage section, any kind of storage technology (e.g. Li-Ion batteries) can be modelled by providing charge/discharge power (in MW) and efficiencies together with the storage capacity, with the option of allowing for simultaneous operation of charging and discharging. The storage cannot provide balancing or flexibility services and its purpose is solely to avoid excess electricity production.

Import & Export

EnergyPLAN sets two technical parameters for the interconnection between the energy system under analysis and the external system:

- Transmission line capacity [MW]: equal for both import and export. Only one "border" can be defined, hence if analysing a country with more than one border, the transmission capacity has to be aggregated;
- Stabilisation share of transmission line [%]: share of the max capacity which contributes to the stabilisation share of the grid

In case of excess electricity production, the order of priority is established as follows:

1. Export;
2. Pumped-hydro storage (when transmission capacity is fully exploited), in combination with battery storage (if specified by the user);
3. In the case the previous two options are not available or already exploited, then the excess electricity production must be curtailed since it cannot be dispatched.

As a consequence, being export the first choice and given the assumption of always having interconnection capacity available, then the export is likely to be overestimated compared to the future expected values. In the technical analysis, import occurs only if the modelled generation system cannot satisfy the demand during a specific hour.

5.1.4 Fuel

The fuel distribution for each technology can be defined and such information can be easily found in the Statistical Pocketbook provided by the European Commission, where gross electricity production divided by fuel/product is specified (European Commission - Energy Datasheet, 2019).

[34] Large power plants including hydro, gas, coal and nuclear, plus CSP and biomass

Additionally, fuel market price can be included in the "Fuel cost" section for the three main energy carriers, such as coal, natural gas and oil and for alternative fuels such as biomass (dry or wet), nuclear (included handling), LPG and diesel. For the purposes of modelling the national energy system up to 2030, pricing forecasts from the EU Reference Scenario 2016 (EUCO30) of the European Commission for the main energy products predictions were used. The cost is assumed constant throughout the year, which differs from the reality (e.g. natural gas is cheaper during the summer and more expensive during the winter).

Table 13 - Forecast for the evolution in the prices of fossil fuels and CO_2 under the EUCO30 Scenario. Source: (European Commission - Reference Scenario, 2016)

	UNIT	2015	2020	2025	2030
Oil (crude)	€/GJ	7.63	11.61	13.18	14.52
Natural Gas	€/GJ	6.6	7.47	8.08	8.79
Coal	€/GJ	1.91	2.21	2.65	3.18
Nuclear	€/GJ	0.47	0.47	0.47	0.47
Emission Allowances	€/ton CO_{2eq}	5.8	15.0-15.5	22.5-23.5	33.5-34.7

With regards to the emission factors per technology, the CO_2 content of the fuels can be obtained as well from the TYNDP 2018, as reported in Table 14.

Table 14 - Emission factors per technology. Source: (ENTSO-E: TYNDP, 2018)

	COAL	NATURAL GAS	OIL	BIOMASS
Kg_{CO2}/net GJ	94	57	74	109.6

5.1.5 General costs

This section contains a database to be filled with general costs for different production technology. Given the similarities in prices, the same cost database will be used for Spain and Portugal. Specifically:

- P_{unit} : investment per unit price (€/MW or €/GWh)
- C_{tech} : capacity installed of the technology under analysis (renewable, non-renewable or infrastructure)
- n : period in years (which depends on the technology)
- $O\&M_{fix}$: fixed Operation and Maintenance cost (expressed as percentage of the total investment and depending on the technology)
- $O\&M_{var}$: EnergyPLAN allows to include additional variable costs that will be added on top of fuel cost and CO2 emission allowances. Unfortunately, coal and NG are aggregated under the same parameter ("Condensing Power Plant", $O\&M_{var\_PP}$), hence the weighted average cost on the installed capacity has been taken into consideration, as shown in the equation below

$$O\&M_{var\_PP} = \frac{C_{coal} * O\&M_{var\_coal} + C_{NG} * O\&M_{var\_NG}}{C_{coal} + C_{NG}} \quad (8)$$

- i : general interest rate (in %), set as 6% for this case study. Interest rates vary depending on the type of technology and source of funding; hence the chosen interest is considered as a good balance value for the whole energy system on the long run. On the other hand, it would be a conservative value for renewables only with the record-low rates of recent years (FS-UNEP, 2018).

Then, EnergyPLAN calculates the total investment cost I_{tech} (in M€), the annual investment cost A_{tech} (in M€/year) and annual fixed O&M cost $A_{O\&M\_tech}$ (in M€/year) for each technology as follows:

$$I_{tech} = P_{unit} * C_{tech} \quad (9)$$

$$A_{tech} = I_{tech} * \frac{i}{1-(1+i)^{-n}} \quad (10)$$

$$A_{O\&M\_tech} = I_{tech} * O\&M_{fix}[\%] \quad (11)$$

Fixed and variable costs of the main technologies for both Scenarios (2016 and 2030) together with their lifetime are included below in Table 15. In this case study, 2017 costs are assumed to be equal to the previous year whilst the column on the right provides general information which do not vary between the two scenarios (lifetime and variable operations and maintenance $O\&M_{VAR}$).

Table 15 - Cost of the main technologies and lifetime. Adapted from: (Draft PNEC, 2018)

TIMES_PT	2016			2030			GENERAL INFO	
V: 18-12-2018	Investment	$O\&M_{FIX}$	%	Investment	$O\&M_{FIX}$	%	Lifetime	$O\&M_{VAR}$
UNIT	M€/MW	€/W	-	M€/MW	€/W	-	Years	€/MWh
Coal	1.9	0.035	1.84%	2.3	0.035	1.52%	30	3.4
Natural Gas	0.8	0.022	2.75%	0.765	0.021	2.75%	30	2.76
Biomass	4.7	0.047	1.00%	4.23	0.04	0.95%	-	0.71
Waste	2.03	0.052	2.56%	2.01	0.044	2.19%	-	0.81
Solar	0.7	0.013	1.86%	0.645	0.0122	1.89%	25	0
CSP	5.1	0.102	2.00%	4.59	0.0918	2.00%	30	0
Wind On-shore	1	0.018	1.80%	0.98	0.018	1.84%	25	0
Wind Off-shore	4.6	0.138	3.00%	2.4	0.072	3.00%	25	0

Hydro	1.4	0.04	2.86%	1.4	0.04	2.86%	50	-
PHES	2.8	0.06	2.14%	2.8	0.06	2.14%	50	-
Batteries (Li)	2.1	0.045	2.14%	1	0.045	4.50%	15	-

5.1.6 Simulation strategy

As anticipated at the beginning of Chapter 5, there are two different simulation strategies that the user can choose from when running an optimisation: technical simulation and market economic simulation.

Technical Simulation

The technical simulation is based on the technical abilities of the components within the energy system with the objective of minimising fossil fuel consumption. The technical simulation strategy is more accurate at simulating energy systems with very large penetrations of intermittent renewable energy, which in combination with the cost data for the technologies, makes it possible for the user to identify least cost solutions over their total lifetime. Hence, this strategy was preferred over the market economic simulation for modelling 2030 Scenarios, but it is less accurate for analysing current energy systems compared to the market economic simulation.

Market Economic Simulation

The Market economic simulation strategy is based on a short-term marginal price market model similar to the NordPOOL market design, so it focuses solely on bids to the electricity market while minimizing short-term electricity costs. As a result, this simulation strategy only uses variable costs and does not optimise based on the long-term costs of different energy supply technologies. Furthermore, it only optimises the supply side of the energy system, and not the demand side. While mathematically it is possible using the price elasticity feature in EnergyPLAN to simulate 100% renewable energy scenarios using the current market design, this may not accurately represent how future energy supply and demand markets should be designed. In fact, today’s markets are primarily designed for dispatchable plants, whereas 100% renewable energy systems will most likely depend on very high levels of non-dispatchable renewable energy (Lund & Thellufsen, 2018).

Logic steps behind the simulation choice

Before diving into the validation and modelling of future Scenarios, it is indeed relevant to provide a detailed explanation on the chronological steps that led to the results shown in Chapter 6 and 7. Firstly, the market economic simulation was chosen over the technical simulation, with the ambition of modelling future market prices and collecting both technical and economic data, as requested by the model input. After obtaining consistent results for the 2017 case study and thus successfully validating the model, then the first attempts to model the Portuguese 2030 Scenarios were made; at this step, since some inconsistencies were found in the model outputs, mainly caused by the unsuccessful efforts to model the future MIBEL price (external market price as explained in Annex 10.3), a different strategy was chosen. In fact, after a more careful reading of the EnergyPLAN documentation and user guide (Lund & Thellufsen, 2018), it was discovered that the technical analysis would have been more accurate for modelling the 2030 Scenarios compared to the market economic analysis, as explained above. Hence, even if not directly affecting the results, all the general cost and emissions data were kept, being an extremely useful source of information for monitoring and evaluating the consistency of the model outputs.

5.1.7 Main output variables

The primary variables chosen to be recorded by the model when comparing alternative energy systems for this case study are:

1. RES [%] : Share of renewable energy in the final energy consumption, value obtained by summing all the contributions from renewable energy sources ($El_{solar} + El_{wind} + El_{biomass} + El_{hydro}$) and dividing them by the total electricity production El_{prod} [in TWh/year]. Additionally, the electricity produced from pumping El_{PHES} must be subtracted taking into consideration the round-trip efficiency η_{PHES} since the model double-counts it as additional renewable energy, which is not coherent with the definition given by the European Commission for accounting the renewable energy share:

$$RES\ [\%] = \frac{El_{solar} + El_{wind} + El_{biomass} + (El_{hydro} - El_{PHES} * \eta_{PHES})}{El_{prod}} \qquad (12)$$

2. EEP : Excess Electricity Production, extra electricity produced that must be exported, stored with pumped hydro or curtailed.

5.2 Energy modelling tools

Due to the wide range of energy tools available online, it is challenging, at the beginning of a study, to select the most suitable, being diverse in terms of the regions they analyse, the technologies they consider, the objectives they fulfil and the methodologies they follow. Thus, it is important to allocate adequate time for the selection process, and if possible, consult the developers of the tools. Consequently, other relevant computer models encountered during this process are listed in the next sub-chapters.

5.2.1 METIS

Developed by a consortium (Artelys, IAEW, ConGas, Frontier Economics) as part of Horizons 2020, METIS consists of a multi-model simulation software that can quickly provide insights and robust answers to complex economic and energy related questions, focusing more on the short-term operation of the energy system and market (Artelys, 2017). METIS is currently owned and operated by the DG ENER from the European Commission, supported by the Joint Research Center (JRC), with the end goal of producing a software that can be used not only by expert modellers, but also policy makers and analysts.

By simulating the operation of energy systems and markets on an hourly base over a year, a detailed analysis of the European energy system for electricity, gas and heat can be provided, while also factoring in uncertainties like weather variations. The METIS software claims to be suitable to assess:

- Impact assessment of Renewable Energy Sources integration to the energy system operation;
- Modelling of electricity and gas markets under different market designs and between different zones;
- Cost-benefit analysis of infrastructure projects, as well as impacts on security of supply;
- Studying the potential synergies between the various energy carriers (electricity, gas, heat);
- Cost and savings of a specific measure for a given year;
- Impact of new energy usages (e.g. electrical vehicles, demand response) on the network reinforcement and generation costs.

In particular, METIS is divided into four different modules that can be run independently from each other: power market module, power system module, heat module and gas module. Being complicated to perform an optimisation of the production plan over multiple years at an hourly time step with 30 assets by country and 34 potential countries, the optimisation problem is solved using a rolling horizon approach, which means that the solution for the whole period is obtained by defining three horizons and solving iteratively smaller problems:

a) **Strategic horizon:** full duration of the entire problem (e.g. one year)
b) **Tactical horizon:** length of the smaller optimisation problems horizon (e.g. 15 days)
c) **Operation horizon:** length of the interval for which the solutions of the small optimisation problem are kept in the full solution (e.g. 7 days)

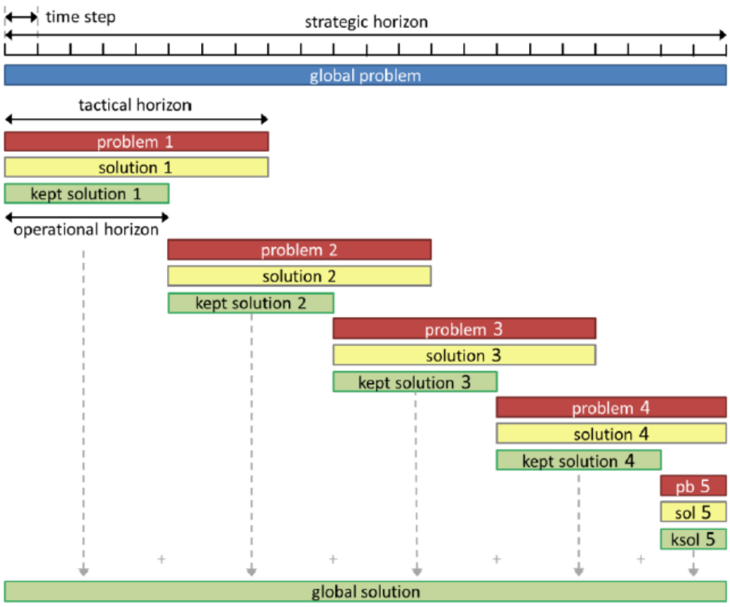


Figure 32 - METIS Optimisation process. Source: (Artelys, 2017)

Unfortunately, being one of the most accurate and validated energy models for Europe, METIS is not a free software, and although the developers were consulted[35], it was not possible to get a licence neither a training for academic

[35] Tobias Bossmann, PhD and Project Manager

purposes. However, good insights were obtained, and the documents released helped to identify possible weak assumptions and to improve the results obtained with EnergyPLAN.

5.2.2 TIMES

The TIMES (Integrated MARKAL-EFOM System) model generator was developed as result of the collaboration between the International Energy Agency (IEA) and the Energy Technology Systems Analysis Program (ETSAP), an international community which uses long term energy scenarios to conduct in-depth energy and environmental analyses. TIMES is a technology rich, bottom-up model generator, which uses linear-programming to produce a least-cost energy system, optimized according to the constraints imposed by the users, over medium to long-term time horizons. The TIMES model generator combines the technical engineering and the economic systematic approach and it is mainly used for the exploration of possible energy futures based on contrasted scenarios (Loulou, Remne, Kanudia, Lehtila, & Goldstein, 2016).

Most of the NECPs are assessed and elaborated using the national TIMES model, initially developed within the European project NEEDS (Gouveia, Dias, Fortes, & Seixas, 2012). The project aimed at creating an integrated pan-European energy model to estimate the full costs and benefits (including externalities) of energy policies and of future energy systems, both at the level of individual countries and for the enlarged EU as a whole (ISIS – Institute of Studies for the Integration of Systems, 2009). Regarding the two Iberian countries, TIMES_PT was developed for Portugal by Júlia Seixas, whilst TIMES-SINERGIA is the model developed for the Spanish energy system.

The primary objective of any TIMES model is the match between supply and demand of energy at the least possible cost, formulating a single, overall mathematical programming problem that seeks to optimize the Net Present Value (NPV) of the energy supply system. Annual flows of energy consumption and production are split by four reference days in the four different seasons (spring, summer, fall, winter) and within each day the night, day and peak load are considered, as depicted in Figure 33.

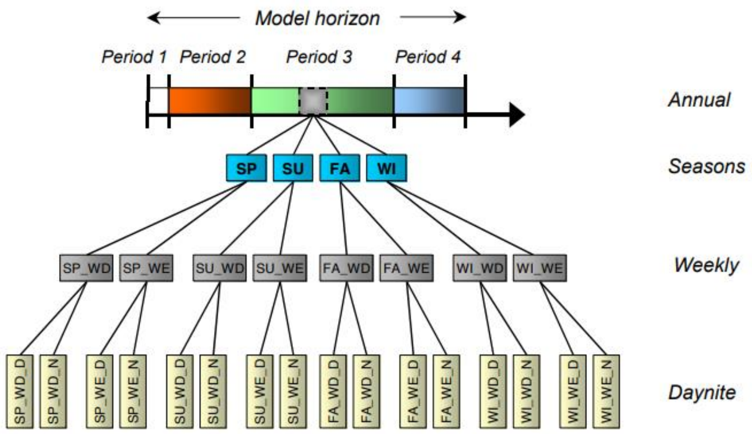


Figure 33 - TIMES Time slice tree. Source: (Loulou, Remne, Kanudia, Lehtila, & Goldstein, 2016)

TIMES was the first energy model considered to pursue this study, however, after a consultation with Professor Patrícia Fortes[36], the model was discarded due to the fact that it would have led to similar results to the ones obtained in the PNEC and in the INECP.

[36] PhD from Universidade Nova de Lisboa who participated in the implementation of TIMES model for Portugal,

6 Validation: modelling year 2017

This chapter will describe the outcomes of the validation of the model on the Portuguese 2017 case study under technical simulation and comparing it with real data taken from the REN report "Eletricidade: Estatística Anual 2009-2018" (REN - Estatística Anual, 2019), which can be found in the Annex 10.2. From the yearly statistics it is possible to obtain data regarding total electricity production (from renewable and not renewable sources), production and consumption from pumped hydro, imports and exports, peak loads, share of renewables, utilisation of the grid and finally capacity installed. In the REN report the following diagrams are included as well: evolution of consumption, breakdown of consumption, installed capacity, load diagram, utilisation of thermal power plants, index of productivity (hydro and wind) and water storage in the reservoirs.

6.1 Portugal: inputs

Firstly, the values included in the REN yearly statistics have been verified for all the technologies and confirmed to be coherent with the cumulative REN hourly values: as shown in Table 16, the total electricity production, the capacity installed, the peak production and the capacity factor (CF) were compared. It is important to mention that the installed capacity specified from REN and DGEG were used as input rather than the maximum peak generation to avoid any additional influence on the model.

Table 16 – Portuguese general yearly energy statistics per technology (2017). Adapted from: (REN - Market Information, 2017) & (DGEG - Installed capacity, 2019)

	UNIT	WIND	SOLAR	HYDRO	BIOM	COAL	NG	EXP.	IMP.	OTHER[37]
Capacity	MW	5099	493	7193	653	1871	4056	2700	3600	-
Peak	MW	4471	403	4700	367	1763	3445	3200	4000	706
Production[38]	GWh	11994	848	5537	2815	13667	13550	5620	2936	4486
CF	-	26.9%	19.6%	11.8%	49.2%	83.4%	38.1%	21.3%	16.8%	-

In particular, from the pumped-hydro generation and consumption data it is possible to compute the average efficiency of the roundtrip process, equal to approximately 80%, value that is confirmed by the literature as well, which suggests an efficiency between 70% and 80% according to the system age (Letcher, 2016) & (Kougias & Szabó, 2017). Table 17 includes all the hydroelectric parameters, which are extremely determinant for the computation of the future capacity factor of the hydropower plants in 2030, which is assumed to be equal to the average over the last 10 years (21.6%), in order to reflect the influence of dry and wet years. The same study assessing the Spanish hydrogeological resources can be found in the Annex 10.4 under Table 28.

[37] Includes cogeneration from natural gas and production from other non-renewable thermal sources.
[38] All the production values were computed from the summation of the hourly values

Table 17 – Portuguese Hydropower and PHES statistics. Adapted from: (REN - Estatística Anual, 2019)

	UNIT	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	AVG
Production	TWh	8.0	15.8	11.2	5.3	13.5	15.3	8.5	15.4	5.5	12.1	-
Water Input	TWh	8.87	17.59	12.49	5.92	14.98	17.02	9.39	17.13	6.15	13.44	-
Capacity	GW	4.99	5.00	5.40	5.67	5.67	5.71	6.16	6.95	7.19	7.22	-
Hours	Hrs	1601	3168	2080	941	2378	2683	1373	2219	770	1677	**1889**
CF	-	18.3%	36.2%	23.7%	10.7%	27.1%	30.6%	15.7%	25.3%	8.8%	19.1%	**21.6%**
Storage	GWh	3066	3100	3059	3080	3080	3092	3070	3208	3192	3180	-
PHES Cap.	MW	983	983	983	1223	1223	1254	1638	2437	2698	2698	-
PHES Prod.	GWh	739	411	587	1114	1157	859	1160	1217	1803	1264	-
PHES Cons.	GWh	929	512	737	1388	1458	1079	1467	1519	2223	1582	-
CF - Pumping	-	10.8%	5.9%	8.6%	13.0%	13.6%	9.8%	10.2%	7.1%	9.4%	6.7%	-
Efficiency	-	79.5%	80.3%	79.6%	80.3%	79.4%	79.6%	79.1%	80.1%	81.1%	79.9%	**79.9%**

The available capacity of import/export is not constant and changes throughout the year, as it can be seen consulting "REN Market Information – Interconnections", and it differs according to the direction of the electricity exchange, as shown in Chapter 3.3. Hence for the validation, the average commercial interconnection capacity of 2017 has been chosen as input, equal to approximately 2500 MW.

By consulting the "REN Market Information – Generation" data (REN - Market Information, 2017), the behaviour and hourly profiles of the different energy sources[39] can be investigated, starting from the hourly distribution of wind and solar (in Figure 34), which have been normalized with the procedure described in Chapter 5.1.2.

[39] Technology breakdown: hydro, pump, solar, wind, biomass, coal, natural gas, import/export, others (not renewable production, included cogeneration)

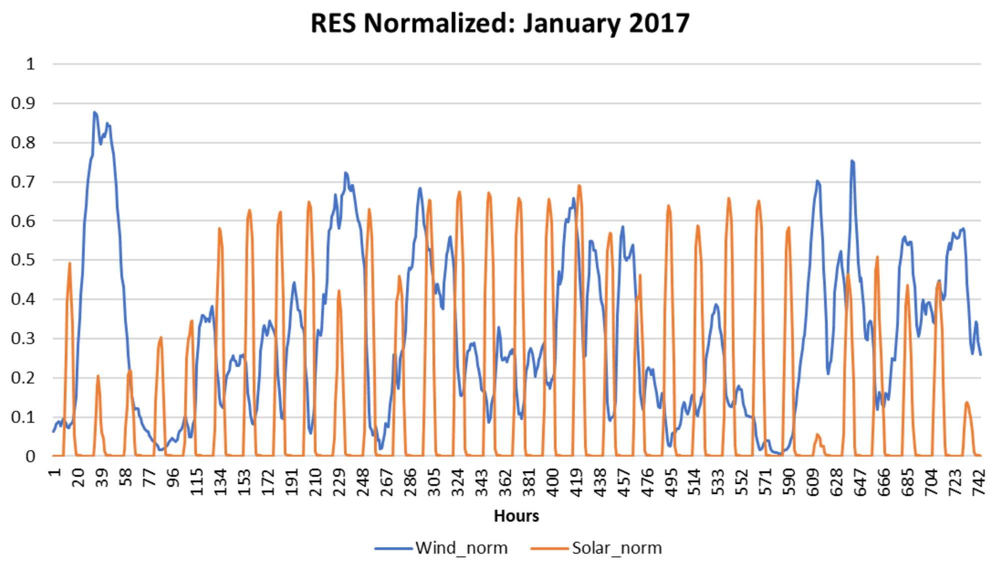


Figure 34 – Portuguese Wind and Solar Distributions Normalized - January 2017. Adapted from: (REN - Market Information, 2017)

Additionally, biomass and cogeneration were also modelled as variable sources, given the availability of hourly distribution: on one hand the average power of the biomass has been identified as 320 MW, with a maximum of 367 MW and a minimum of 199 MW[40] during 2017; on the other hand, cogeneration is characterized by a power output between 300 MW and 700 MW, alternating peak during the day and off-peak during the night. As example, the generation profile of January 2017 is shown in Figure 35 for both technologies.

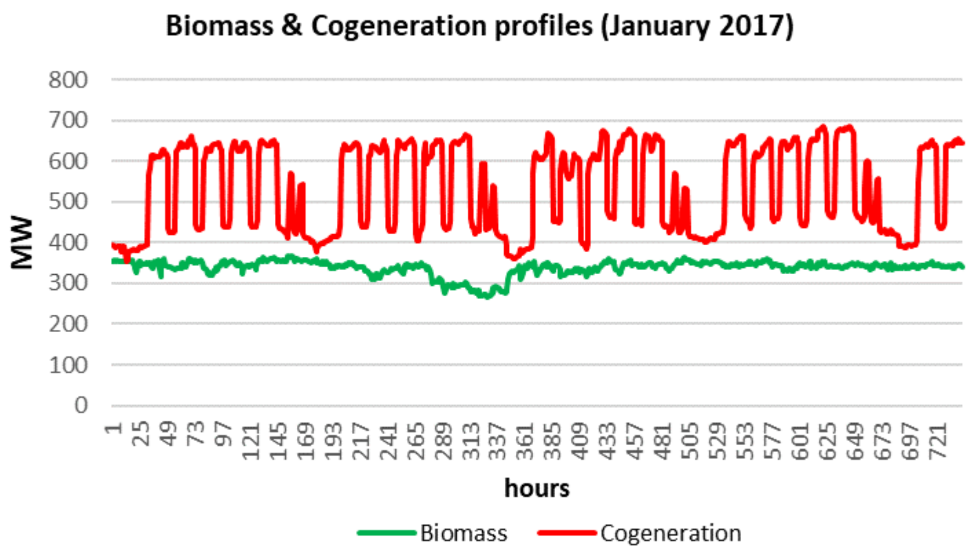
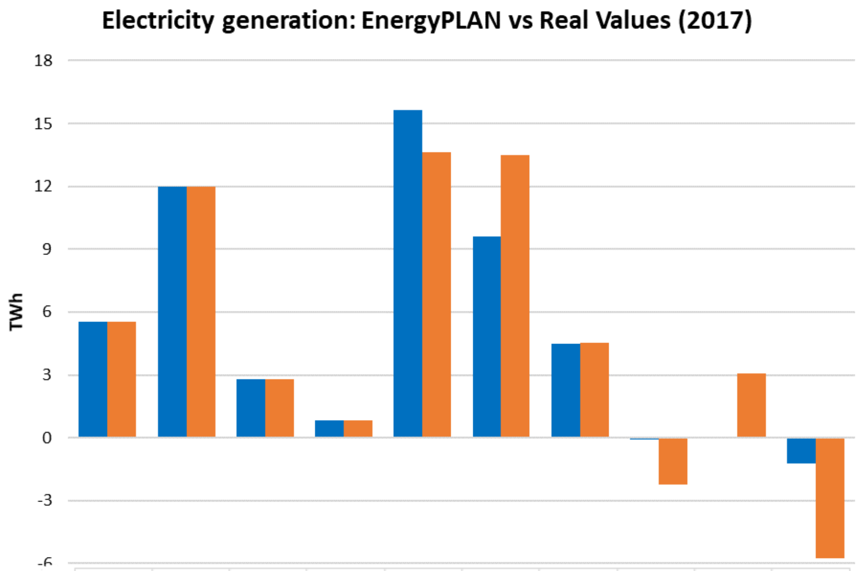


Figure 35 – Biomass and Cogeneration generation profiles (January 2017). Adapted from: (REN - Market Information, 2017)

[40] Biomass is modelled with a constant output throughout all the year

6.2 Portugal: outputs & comparison

This subchapter provides an overview of the EnergyPLAN technical modelling output, given the inputs described in Chapter 5 and 6, comparing respectively the electricity and peak generation to the real values provided by REN.



	Hydro	Wind	Biomass	PV	Coal	NG	Cog	Pumping	Import	Export
EnergyPLAN	5.5	12.0	2.8	0.85	15.6	9.6	4.5	-0.1	0.0	-1.2
REN	5.5	12.0	2.8	0.85	13.6	13.5	4.5	-2.2	3.1	-5.8
Error	0.3%	0.0%	-1.1%	0.7%	-14.9%	28.9%	0.5%	-96%	100%	79%

Figure 36 - Comparison between modelled and real data for electricity generation & Import/Export

The error specified below Figure 16 was computed as follows:

$$Error\ [\%] = \frac{El_{prod\_REN} - El_{prod\_EnergyPLAN}}{El_{prod\_REN}} * 100 \qquad (13)$$

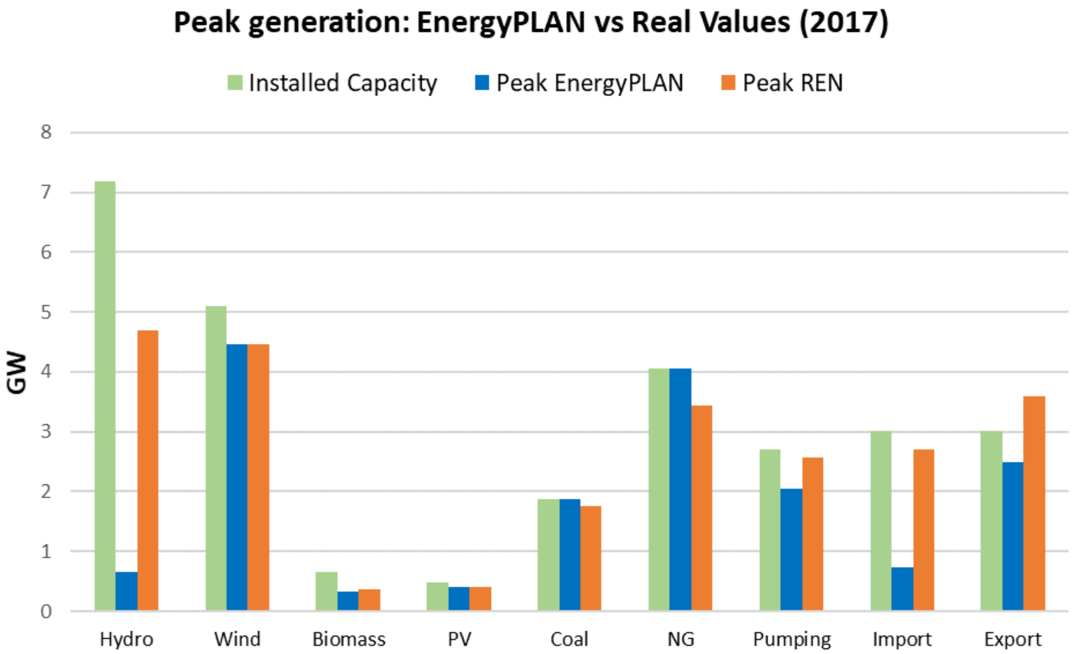


Figure 37 - Comparison between installed capacity and peak generation: EnergyPLAN vs REN Real Values

From Figure 36 and Figure 37 it is observable that:

- **Variable Renewable Energy (solar and wind)**: the error in close to zero since distribution profiles were built using the verified production from REN data;
- **Biomass and Cogeneration:** being modelled as variable energy sources, the electricity generated is coherent with real values. Biomass has a peak load difference of approximately 50 MW, since its output is constant throughout the year;
- **Power Plants (PPs)**
  - **Coal**: coal has been given priority in the model over others fossil fuels powered grid stabilising technologies, leading to a higher electricity generation compared to the real values and a CF close to 100%. The main reason is that minimum time on/off, start-up fuel consumption and fixed cost, minimum stable generation, ramp up/down rate, forced outage and planned maintenance cannot be included in the modelling (same for any other thermal power plant). Additionally, by checking the 2017 power plant operation, it can be noticed that the peak is different from the total capacity (respectively 1756 MW vs 1871 MW) and that the plant operated often at 1460 MW, as shown in Figure 38. If this correction is made, the error decreases from 19% to 12%. However, coal will not be relevant for the 2030 scenario, considering the planned coal phase-out specified in both NECPs;

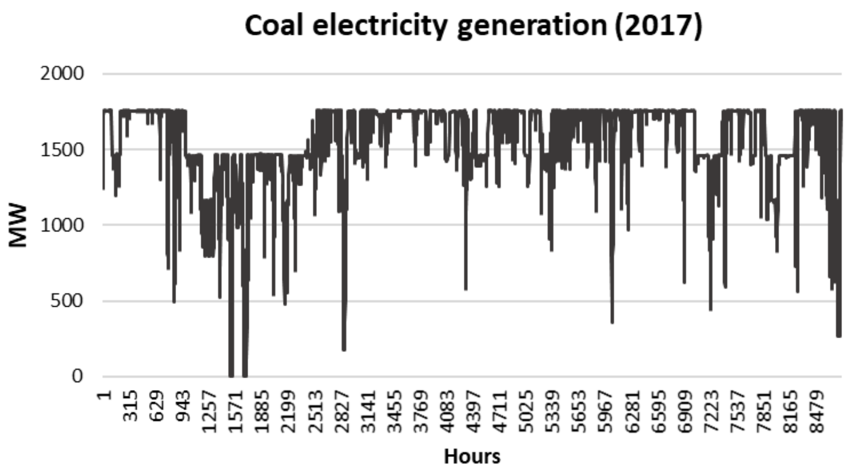


Figure 38 - Coal generation (2017). Adapted from: (REN, 2017)

  - **Natural Gas**: NG is the 2nd technology to provide grid stabilisation after coal. The difference between the results and real values is influenced by the extra production of coal.
  - **Hydropower:** since its production depends by the water input, the final electricity production is almost equal to REN values. With regards to peak generation, hydropower keeps a constant output of around 700 MW throughout the year, as a consequence of the model methodology: in fact, before starting the hourly modelling, the highest possible production is identified given water input, turbine capacity and water storage capacity. In the case of a generation system characterized by a higher share of synchronous generation (coal and natural gas), the latter one is considered more “flexible” technology than hydro and then it is the one following the demand curve. However, this behaviour does not occur for system with high penetration of renewables;

- **Import and Export:** given the fact that only one transmission capacity can be inputted (instead of one for export and one import) and that is constant throughout the year, an error is already introduced in the model, as it is observable comparing the real export peak, which is different between import and export. Export and import have high errors when modelling current energy systems with the technical simulation: in fact, export occurs only in case of excess of electricity (namely if the variable electricity production is higher than 50% of the total demand, value equivalent to the minimum grid stabilisation factor), import only in the case if the system cannot satisfy the electricity with its own generation system.

Overall, the model is considered tuned for the Portuguese case study, although for export import and pumping it incurs in considerable errors given the limitations on modelling inputs. differs greatly from real values, especially for export, import and pumping. However, as stated in Chapter 0, the technical analysis is not the most accurate for modelling current energy systems; in fact, the market economic analysis, which initially was performed before the technical analysis, leads to lower errors with regards for export, import and pumping, as shown in Annex 10.3. For this reason, the technical validation was only performed for Portugal and not for Spain.

7 Future Scenarios: 2030 modelling, results and discussion

Chapter 7 shows the implementation of the technical analysis on the Iberian case study and presents the outcomes of the 2030 Scenarios. As first step, the 2030 Scenario for Portugal will be generated. Since the PNEC does not distinguish clearly between Baseline and Target Scenario, neither provides a detailed description to comply with general and sector estimated trajectories per renewable energy technology for the 2030 horizon. All the technologies have a fixed target, except for solar (between 7.8 and 9.3 GW), wind (between 8.8 and 9.2 GW) and other renewables (see Table 7), which however are not modelled for this case study. Hence, given the fact that the two ranges are specified for wind and solar, two different Scenarios will be generated: a Low-RES and a High-RES Scenario. Unfortunately, since TIMES_PT model results are not specified in the PNEC, the result could not be compared for the Portuguese case. A sensitivity analysis between these two Scenarios will follow, focusing on how different capacities of wind and solar affects the excess of electricity and on the effect of a dry/wet year on the RES share. Afterwards, the Baseline and Target Scenarios Spain will be generated. Then, the two countries will be coupled to model the Iberian Peninsula, aggregating the capacity installed, the distribution profiles and the demand curve.

All the Scenarios are analysed in two different modalities: interconnected and island mode. The main reason behind this modelling choice is to analyse how the excess electricity production (EPP) is managed by a certain energy system according to its boundary conditions. In fact, there are three possible options for solving the electricity excess problem, bringing back the system to balance: exporting electricity, increase the consumption through pumping or curtailing the wind or solar farm output. Regardless the Scenario or the simulation performed (interconnected or island mode), the excess electricity production (EEP) is always equivalent to the sum between electricity exported (El_{export}), electricity consumed by pumping ($El_{pumping}$) and critical excess electricity production ($CEEP$), as shown in equation 14 and verified in all the simulations:

$$EEP = El_{export} + El_{pumping} + El_{storage} + CEEP \ \ [TWh] \quad (14)$$

The procedures and the methodology for inputting data for the generation of the 2030 Scenario are resumed below:

- **Electricity demand:** as described in Chapter 5.1.1, the load forecasted by the ENTSO-E TYNDP Sustainable Transition Scenario will be used, assuming normal hydro climate condition (between wet and dry), as reported in Table 18;

Table 18 - Electricity demand in 2030 for the Sustainable Transition Scenario. Source: (ENTSO-E: 2030 Loads, 2018)

	UNIT	PORTUGAL	SPAIN	IBERIA
El_{demand}	*TWh*	53.74	284.75	338.49
Max Load	*MW*	10008	46595	56460
Min Load	*MW*	3561	20420	24881

- **Generation system:** Table 7 (Portugal) and Table 9 (Spain) from Chapter 4.1.2 and 4.2.2 contain the information regarding the expected capacity in 2030;
- **Variable Renewable Energy:** the same normalized distribution profile built for the 2017 will be kept for 2030. Additionally, a correction factor of 0.1 (see equation 6) will be applied to model an improvement in the technology, enabling a slightly higher capacity factor for wind and solar compared to 2017;
- **Hydropower:** as explained in Chapter 5.1.2, hydropower output is determined by the water supply established by the user. Hence, the water supply for 2030 is calculated using the average capacity factor CF_{avg} over the 10-year window (2009-2018) and the planned installed capacity C_{hydro_2030}, as shown in Table 17. Equations 13 and 14 provide the calculation for the Portuguese and Spanish cases:

$$W_{supply\_2030\_PT} = \frac{C_{hydro\_2030\_PT} * CF_{avg\_PT} * 8760\ hrs}{\eta_{hydro}} = 18.29\ TWh/year \quad (15)$$

$$W_{supply\_2030\_ESP} = \frac{C_{hydro\_2030\_ESP} * CF_{avg\_ESP} * 8760\ hrs}{\eta_{hydro}} = 34.27\ TWh/year \quad (16)$$

- **Water reservoir:** since no quantitative values are specified by the PNEC or INECP, the water storage capacity will be kept the same as to 2017, assuming once again to start the year with 50% filled water reservoir, value that is coherent under average hydrogeological condition (REN - Market Information, 2017) (RED - Report, 2019);
- **Cogeneration:** for 2030, cogeneration will be aggregated together with natural gas for both Spain and Portugal, hence no fix distribution will be imposed, as done for 2017, to allow the energy system to operate in a more flexible way. In fact, if on one side specifying the cogeneration hourly distribution allows to achieve an improvement on the modelling performance for 2017, on the other side it would lead to an overestimation of the electricity excess for the future Scenario. Furthermore, since cogeneration is not specified in the Portuguese 2030 generation system and it was not possible to build Spanish cogeneration profile due to lack of data, it was decided to keep a coherent approach for the two Iberian countries;
- **Technology and fuel costs:** Table 15 specifies the cost of the main technologies, whilst the forecasted fuel prices are included in Table 13. These parameters do not actively participate in the optimisation, but can help the user when analysing modelling outputs;
- **Interconnection:** Chapter 3.3 contains information regarding planned interconnection capacity for Portugal-Spain, Spain-France and Portugal-Morocco. For the analysis, Morocco interconnection will not be considered for both Portugal and Spain, given the uncertainty of the project realisation for Portugal and the fact that exchanges with Morocco were not modelled by the INECP as well, as stated in Chapter 4.3.2;
- **Grid stabilisation share:** as specified in Chapter 5.1.3, the initial stabilisation share will be set to 50% for the Spain 2030 Baseline Scenario, while a 30% share was considered for the Spain 2030 Target Scenario and for both Portugal 2030 low-RES and high-RES Scenario. The minimum grid stabilisation share f_{grid} has been lowered for the Target Scenario to reflect technological improvements and investment in the grid and maintained equal between interconnected and island mode so that the two case studies are characterized by the same assumptions (except for the interconnection capacity) and can be effectively compared;

- **Pumping:** pumping has the role to remove excess electricity production from the system;
- **Critical Excess Electricity Production (CEEP):** this parameter is introduced to expresses the amount of electricity that could not either be pumped or exported and therefore must be curtailed from RES (wind or solar) to achieve the electricity balance.

The modelling outcomes of each Scenario are presented in different tables, where the following data will be included and divided by technology, and compared in terms of:

- Installed capacities C_{inst};
- Electricity production El_{prod} and production shares;
- Capacity factors (CF) and Full Load Operation Hours (FLH);
- Pumping, export and critical excess electricity production (CEEP).

7.1 Portugal: 2030 Scenario

7.1.1 Low-RES Scenario

Table 19 presents the 2030 modelling results for the Low-RES Scenario.

Table 19 - Portugal 2030 Low-RES Scenario: main parameters - Interconnected vs Island mode

		INTERCONNECTED				ISLAND MODE			
	C_{inst}	El_{prod}	Share	CF	FLH	El_{prod}	Share	CF	FLH
Unit	*GW*	*TWh*	*%*	*%*	*hrs*	*TWh*	*%*	*%*	*hrs*
Hydro	8.7	16.2	25.8%	21.2%	1858	16.0	28.1%	21.0%	1841
Wind	8.8	22.0	35.0%	28.5%	2497	22.0	38.5%	28.5%	2497
Biomass	0.5	3.7	5.9%	84.0%	7358	3.7	6.4%	84.0%	7358
Solar PV	7.8	14.1	22.4%	20.6%	1802	14.1	24.6%	20.6%	1802
CSP	0.3	0.80	1.3%	30.3%	2652	0.80	1.4%	30.3%	2652
NG	2.8	6.0	9.6%	24.5%	2150	0.5	0.9%	2.2%	191
Pumping	3.6	-1.7	-	5.6%	488	-8.9	-	28.3%	2482
Export	3.6	-8.91	-	28.2%	2474	0	-	0.0%	0
CEEP	-	**-0.20**	-	-	-	**-1.97**	-	-	-

From Table 19, it can be noticed that island mode forces pumped hydro to operate when there is excess of electricity from wind or solar. In this case, the extra electricity is kept within the Portuguese system, rather than exporting it: as a consequence, hydro substitutes NG for managing the grid stability, often operating together with the pumps. Critical Excess Electricity Production (CEEP) is highlighted in red since it represents the electricity that must be curtailed from wind and solar to keep the energy balance, hence causing the reduction of the final electricity generated by that technology, consequently decreasing its capacity factor and the final RES share as well.

Figure 39 shows the electricity production breakdown in both cases, highlighting the electricity coming from renewable sources (RES) and from thermal non-renewable (NFRE), whilst Table 20 summarized the main outcomes of the Low-RES 2030 Scenario, distinguishing between interconnected and island mode.

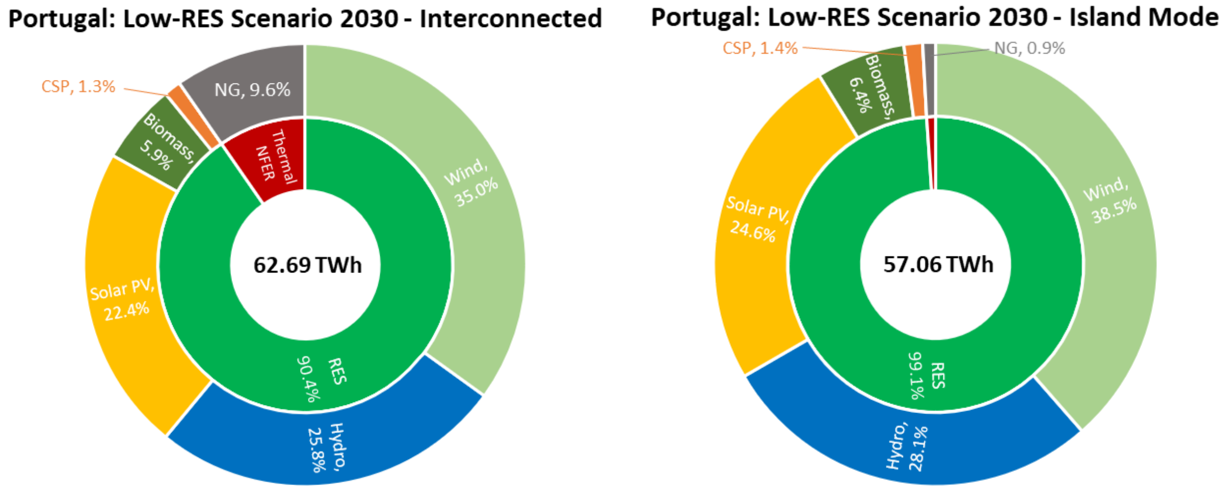


Figure 39 - Portugal 2030 Low-RES Scenario: Electricity production breakdown (without cogeneration) – Interconnected vs Island Mode

Table 20 - Portugal 2030 Low-RES Scenario: main outcomes

	INTERCONNECTED	ISLAND MODE
RES Share[41]	90.4%	99.1%
Grid stabilisation	Achieved: 30%	Achieved: 30%
$El_{production}$	Higher compared to island mode, since export through the interconnection keeps the energy balance within the system	The match between demand and supply (53.33 TWh) can be verified by subtracting the critical excess electricity production and the losses during the pumping process (which given the 80% roundtrip efficiency established for PHES leads to 20% losses during the process of charge and discharge)
Renewables	Wind, solar PV, biomass and CSP have identical electricity generation and CF, varying slightly the shares between interconnected and island mode (due to different final electricity produced)	

[41] Not considering cogeneration

Pumping	Relatively low CF (5.6%), since most of the extra electricity is exported (export has priority over pumping)	Due to the unavailability of interconnections, pumped hydro achieves a high CF (28.3%, almost three times the current average CF for PHES in Portugal)
NG Power Plant	Lower CF (24.5%) compared to 2017 (38.1%) (REN - Market Information, 2017)	Extremely low CF (2.2%), since it is substituted by hydropower to achieve the grid stabilisation share, which becomes possible due to the additional water pumped in the reservoir
Export	Export: 14.3% of total electricity production	No export
Import	Small import (70 GWh) during the dry season. In the interconnected case, the needed electricity is simply imported; in island mode, since the system is not able to satisfy the demand, "critical" import is needed for the energy balance of the system. However, this is caused by an extremely rare case of low RES and almost empty reservoir, which is a direct consequence of how water input was modelled (low precipitations during summer means lower water input). This problem disappears if a constant inflow is applied throughout the year.	
CEEP	A relatively small amount of electricity (0.2 TWh) could not be exported or pumped since all the capacities are already fully exploited, hence this quantity must be curtailed	Compared to interconnected mode, a higher CEEP occurs (1.97 TWh), which must be curtailed from wind or solar

The absence of cogeneration (which is based mainly on natural gas) is the main cause of the renewable share overestimation in the final electricity consumption: actually, cogeneration in Portugal consists of between 10 and 15% of the final electricity production, of which 75% is generated with natural gas (the remaining with biomass) (Draft PNEC, 2018). Moreover, the PNEC have not included cogeneration in the planned generation system (see Table 7), hence this capacity was missing in the modelling as well. Therefore, if cogeneration is included and it is assumed to not contribute to grid stability (since it follows the heat load as shown in Figure 35), then it would cause the final RES share to decrease approximately by maximum 10%, assuming that cogeneration fuel structure won't change in the future compared to 2017 and therefore remaining a constant source of Thermal NFRE electricity.

Therefore, with the capacities referred by the PNEC and according to the results obtained by model, Portugal is then expected to achieve the 2030 target even with the low-RES Scenario. However, this achievement will strongly depend on the future market structure, on the availability of exporting excess electricity to Spain and on the average hydrogeologic conditions of the next decade. As it can be seen from Figure 40, which was built under the assumption of no RES curtailment, no changes in the current fuel cogeneration structure and low-RES Scenario, the final renewable share is strongly influenced by the hydropower electricity production. In particular, the blue line ("no cogeneration") represents the results obtained with the generation system specified in Table 19, whilst the orange line ("including cogeneration") is the result of the adjustment if cogeneration is included in the modelling, under the assumptions described in the previous paragraph.

The achievement of the 80% target of RES in the electricity mix will be guaranteed only if the index of hydro productivity will not decrease (represented by the yellow dashed line) in the next decade. On one hand, if curtailment occurs, then the blue line would shift down; on the other hand, if biomass will increase in the future cogeneration fuel composition, then the orange line would shift up.

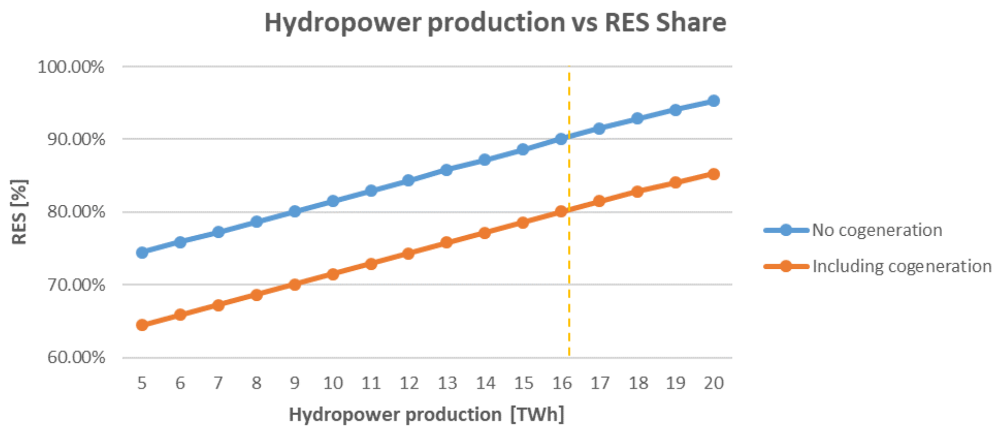


Figure 40 - Correlation between hydropower production and RES Share for Portugal (with interconnections)

7.1.2 High-RES Scenario and sensitivity analysis

In this subchapter, the effect of additional variable renewable energy installed capacity for the Portuguese system will be analysed. In the absence in PNEC of referencing other energy storage technologies, an increase of the renewables penetration will lead, as expected, to a great dependence on pumping or exports. If considering the islanded model, pumping will increase (if available), while if considering an interconnected model, the electricity exports will take a major role. In both settings, an increase in the pumped hydro full load operation hours (capacity factor) is expected.

An explanation on how the main computational steps performed by the model to compute the electricity excess is necessary. First, the model computes the electricity needed from synchronous generators $El_{stab,k}$ (natural gas, hydropower, biomass or CSP for the Portuguese case) to comply with the grid regulation, based on the hourly demand $El_{demand,k}$:

$$El_{stab,k} = f_{stab} * El_{demand,k} \quad (17)$$

Then, the electricity coming from variable renewable energy sources $El_{RES,k}$ is added on top of the $El_{stab,k}$ until it reaches the demand ($El_{demand,k}$). If the demand it is not satisfied, then other electricity is generated from central power plants according to the their availability; if the $El_{RES,k}$ plus $El_{stab,k}$ is greater than the $El_{demand,k}$, then excess electricity production occurs. In this case, if the electricity is exported or pumped, then it always must be ensured that 30% of the total energy produced comes from the grid stabilising units. If this electricity excess is immediately curtailed, then there is no need for the grid stabilising units to increase the electricity output to maintain the 70/30 ratio. Hence, the excess electricity production presented in the table must be adjusted (EEP_{adj}) according to the equation below, if our objective is to compute the real excess of electricity:

$$EEP_{adj} = EPP * (1 - f_{grid}) \tag{18}$$

Table 21 demonstrates how the installed capacity of wind and solar affects the excess of electricity production (with respect to the electricity demand profile defined by the TYNDP), keeping 30% as grid stability share. Here, it can be seen that the Low-RES Scenario (highlighted in yellow) would lead to an electricity excess of 10.86 TWh, whilst in the High-RES Scenario (+0.4 GW of wind and +1.5 GW of solar) this value would increase up to 15.1 TWh (highlighted in red) (additional 4.24 TWh).

Table 21 – Correlation between Excess Electricity Production and wind/solar installed capacity

	SOLAR PHOTOVOLTAICS									
	GW	**7.8**	**8**	**8.2**	**8.4**	**8.6**	**8.8**	**9**	**9.2**	**9.3**
WIND	**8.8**	**10.86**	11.3	11.7	12.2	12.63	13.08	13.5	14.0	14.2
	8.9	11.08	11.5	12.0	12.4	12.85	13.3	13.8	14.2	14.4
	9	11.3	11.7	12.2	12.6	13.07	13.53	14.0	14.4	14.7
	9.1	11.53	12.0	12.4	12.9	13.3	13.76	14.2	14.7	14.9
	9.2	11.75	12.2	12.6	13.1	13.53	13.98	14.4	14.9	**15.1**

7.2 Spain: 2030 Scenario

For Spain, the INECP provides much more detail on the 2030 scenarios, even specifying per technology the production shares. Thus, in this chapter the Baseline and Target Scenarios are compared to the INECP values.

7.2.1 Baseline Scenario

As motivated at the beginning of the chapter, a higher grid stabilisation share (50%) was set for the Baseline Scenario, assuming that the current grid infrastructure will not be improved to accommodate a higher penetration of renewables, which means that 50% of the electricity must always come from synchronous generation, such as coal, NG, nuclear. Table 22 presents the main parameters obtained from the simulation of the 2030 Baseline Scenario, whilst Figure 41 and Figure 42 provide the comparison of electricity production for interconnected, island mode and INECP values, respectively in shares (%) and in absolute values (TWh).

Table 22 - Spain 2030 Baseline Scenario: main parameters - Interconnected vs Island mode vs INECP

		INTERCONNECTED				ISLAND MODE				INECP			
	Cap.	**Prod.**	**Share**	**CF**	**FLH**	**Prod.**	**Share**	**CF**	**FLH**	**Prod.**	**Share**	**CF**	**FLH**
Unit	*GW*	*TWh*	*%*	*%*	*hrs*	*TWh*	*%*	*%*	*hrs*	*TWh*	*%*	*%*	*hrs*

Hydro	20.1	30.8	10.1%	17.5%	1530	30.7	10.3%	17.5%	1529	28.3	9.6%	16.1%	1407
Wind	38	84.3	27.6%	25.3%	2219	84.3	28.3%	25.3%	2219	91.0	30.8%	27.3%	2394
Biom.	0.9	4.9	1.6%	62.8%	5499	4.9	1.7%	62.8%	5499	4.7	1.6%	59.8%	5238
PV	18.4	33.2	10.9%	20.6%	1802	33.2	11.1%	20.6%	1802	33.1	11.2%	20.5%	1798
CSP	2.3	6.2	2.0%	31.0%	2712	6.2	2.1%	31.0%	2712	5.0	1.7%	24.7%	2160
NG	32.1	53.1	17.4%	18.9%	1655	46.3	15.5%	16.5%	1442	47.6	16.1%	16.9%	1484
Coal	4.5	38.5	12.6%	97.6%	8546	38.2	12.8%	97.0%	8494	23.8	8.1%	60.4%	5293
Nucl.	7.4	54.3	17.8%	83.8%	7342	54.3	18.2%	83.8%	7342	57.7	19.5%	89.0%	7796
Other	-	-	-	-	-	-	-	-	-	4.3	1.5%	-	-
Pump.	6	-3.1	-	5.9%	520	-12.0	-	22.8%	1998	-5.9	-	11.1%	976
Exp.	11.6	-18.2	-	17.9%	1571	0	-	0.0%	0	-28.9	-	28.4%	2490
Imp.	11.6	-	-	-	-	-	-	-	-	21.0	-	20.7%	1814
CEEP	-	**-1.76**	-	-	-	**-11.12**	-	-	-	-	-	-	-

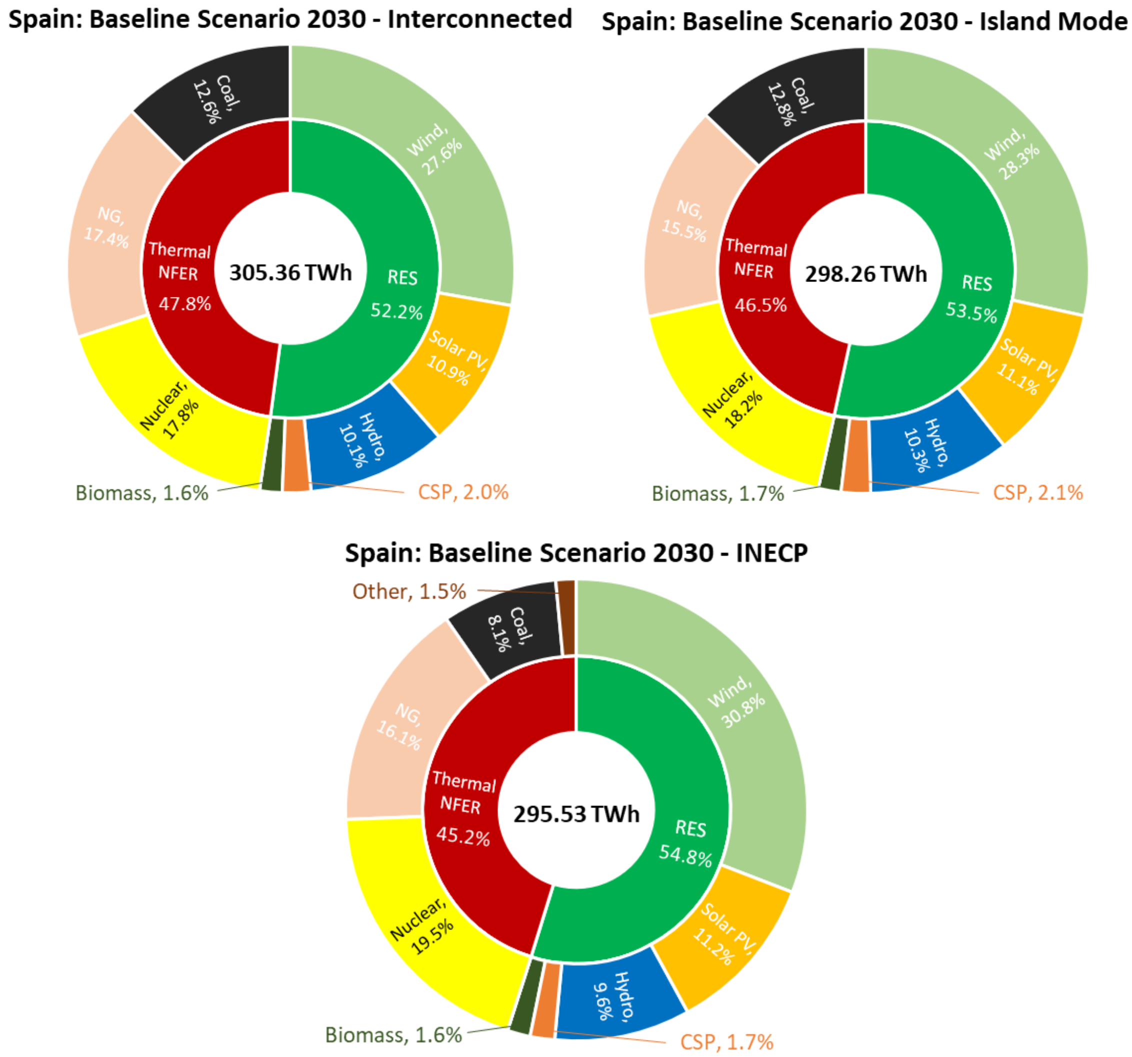


Figure 41 - Spain 2030 Baseline Scenario: electricity production breakdown -Interconnected vs Island mode vs INECP

As it can be seen from Figure 41, there is no substantial difference in the electricity breakdown of the three simulations, where both shares and final electricity production are relatively similar. The detailed discussion on the results and comparison between the two Scenarios (Baseline and Target) for interconnected, island mode and INECP values can be found under Table 24 in Chapter 7.2.3.

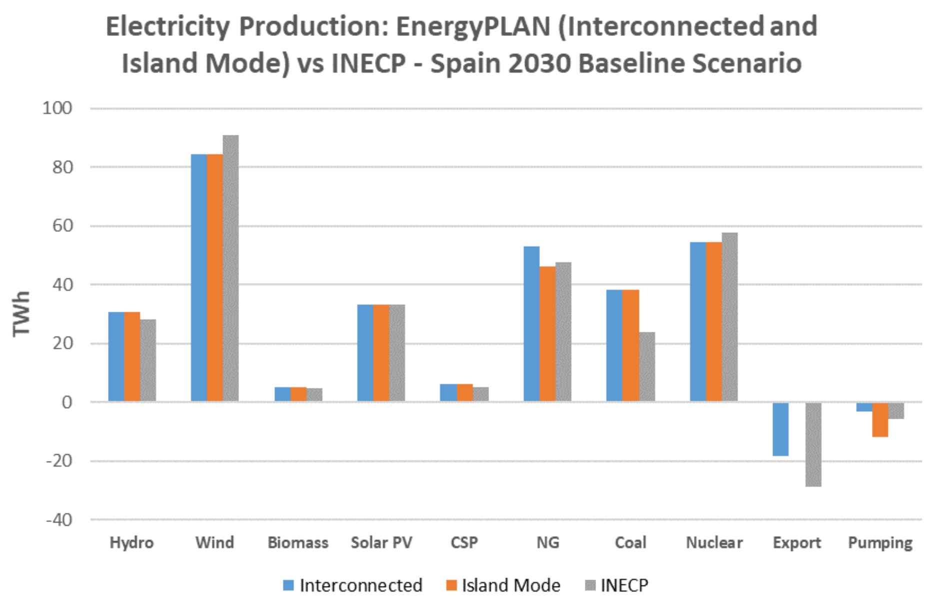


Figure 42 - Spain 2030 Baseline Scenario: electricity production - Interconnected vs Island mode vs INECP

7.2.2 Target Scenario

As referred previously, for the Target Scenario, the grid stabilisation share is lowered to 30%. Moreover, with the additional information provided by the INECP 2.5 GW of batteries were included to the energy system assuming Lithium-Ion battery as technology, allowing to compute the equivalent storage capacity (2 hours at full charge) as follows:

$$E_{cap} = \frac{C_{bat} * 2\ hrs}{\eta_{discharge}} = 5.3\ GWh \quad (19)$$

- E_{cap} : storage capacity of the battery (in GWh);
- C_{bat} : capacity of the battery (in GW);
- $\eta_{discharge}$: efficiency of discharge (assumed 95%, which is equivalent to half of the roundtrip efficiency of a Tesla Powerpack system) (TESLA, 2019).

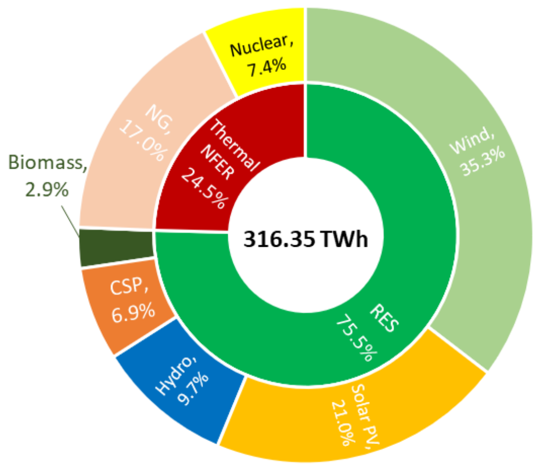
Table 23 shows the main outcomes of the 2030 Target Scenario simulation and Figure 44 depicts the value obtained for electricity production respectively for interconnected, island mode and the ones provided by the INECP.

Table 23 - Spain 2030 Target Scenario: main parameters - Interconnected vs Island mode vs INECP

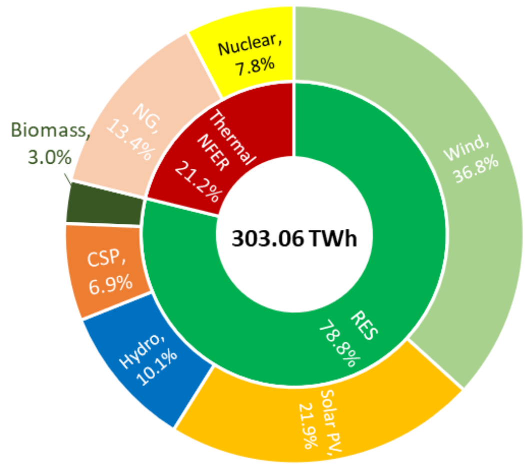
		INTERCONNECTED				ISLAND MODE				INECP			
	Cap.	**Prod.**	**Share**	**CF**	**FLH**	**Prod.**	**Share**	**CF**	**FLH**	**Prod.**	**Share**	**CF**	**FLH**
Hydro	24.1	30.7	9.7%	14.6%	1275	30.7	10.1%	14.5%	1273	29.0	8.8%	13.8%	1205
Wind	50.3	111.6	35.3%	25.3%	2219	111.6	36.8%	25.3%	2219	116.1	35.3%	26.4%	2308
Biom.	1.7	9.2	2.9%	62.6%	5485	9.2	3.0%	62.6%	5485	10.7	3.3%	72.9%	6389
PV	36.9	66.5	21.0%	20.6%	1802	66.5	21.9%	20.6%	1802	66.4	20.2%	20.5%	1799

CSP	7.3	20.8	6.6%	32.6%	2855	20.8	6.9%	32.6%	2855	22.6	6.9%	35.3%	3093
NG	32.5	53.9	17.0%	18.9%	1659	40.7	13.4%	14.3%	1252	54.5	16.6%	19.1%	1677
Nucl.	3.2	23.5	7.4%	83.8%	7342	23.5	7.8%	83.8%	7342	24.8	7.5%	88.5%	7750
Other	-	-	-	-	-	-	-	-	-	4.9	1.5%	-	-
Pump.	9.5	-8.2	-	9.9%	863	-24.0	-	28.8%	2527	-10.4	-	12.6%	1100
Batt.	2.5	-0.62	-	2.8%	248	-1.32	-	6.0%	530	-	-	-	-
Exp.	11.6	-27.2	-	26.8%	2347	0	-	0.0%	0	-48.0	-	47.3%	4142
Imp.	11.6	-	-	-	-	-	-	-	-	8.5	-	8.4%	732
CEEP	-	**-2.68**	-	-	-	**-13.39**	-	-	-	-	-	-	-
Unit	*GW*	*TWh*	*%*	*%*	*hrs*	*TWh*	*%*	*%*	*hrs*	*TWh*	*%*	*%*	*hrs*

Spain: Target Scenario 2030 - Interconnected



Spain: Target Scenario 2030 - Island Mode



Spain: Target Scenario 2030 - INECP

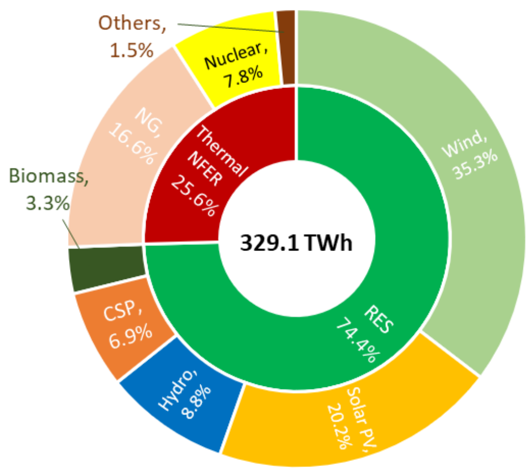


Figure 43 - Spain 2030 Target Scenario: electricity production breakdown - Interconnected vs Island mode vs INECP

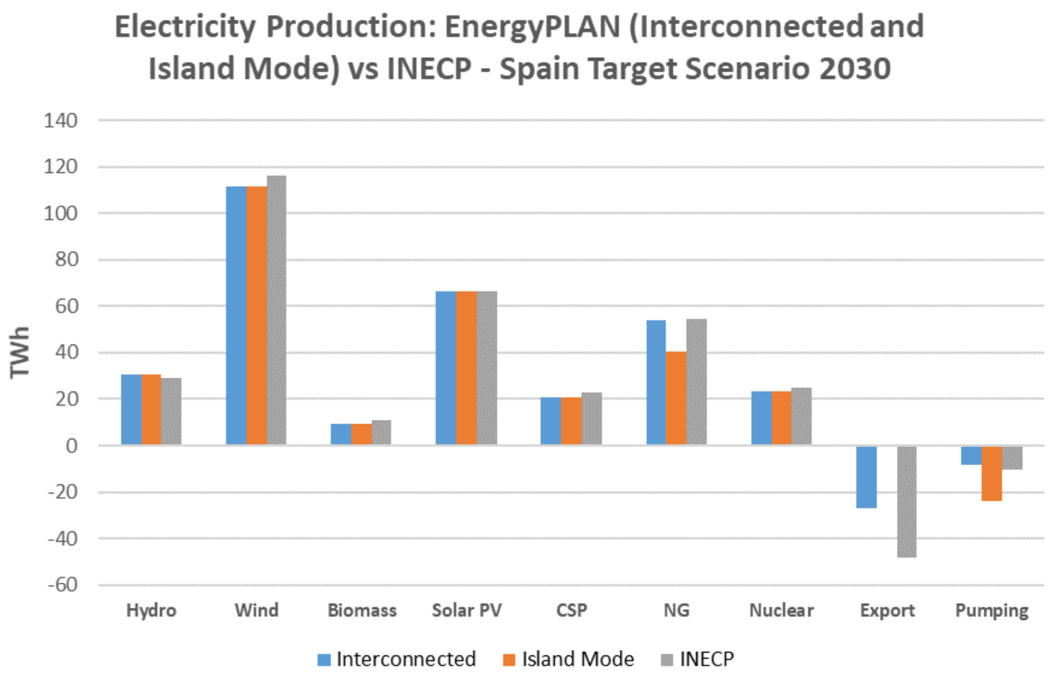


Figure 44 - Spain 2030 Target Scenario: electricity production - Interconnected vs Island mode vs INECP

7.2.3 Comparison between Scenarios

Table 24 contains the comparison between the three Scenarios (interconnected, island mode and INECP), summarizing and commenting the differences between the results obtained.

Table 24 – Spain 2030 Baseline and Target Scenario: comparison between interconnected, island mode and INECP

	BASELINE SCENARIO	**TARGET SCENARIO**
RES Share	Higher in island mode (53.5%) compared to interconnected (52.2%)	Higher in island mode (78.8%) compared to interconnected (75.5%)
Electricity produced	Higher in the interconnected (305.26 TWh) compared to the island mode (298.26 TWh) and the INECP (295.53 TWh)	Higher in the INECP (329.08 TWh) compared to the interconnected (316.35 TWh) and island mode (303.06 TWh)
Grid Stabilisation	50%	30%
CEEP	Electricity that cannot be exported or pumped and therefore must be curtailed. Higher in island mode (11.12 TWh) compared to interconnected (1.76 TWh) due to the need of RES curtailment. If the grid stabilisation share is lowered, then also the CEEP would decrease Parameter not specified by the INECP	Higher in island mode (13.39 TWh) compared to interconnected (2.68 TWh) due to the need of RES curtailment. Parameter not specified by the INECP

Hydropower	Overestimated in the generated scenarios compared to the INECP (+1.7 TWh)	Still overestimated in the generated scenarios compared to the INECP, but slightly higher production due to the additional 0.5 GW of installed capacity between Baseline and Target Scenario
Wind	Underestimated compared to the INECP, which forecasts a higher CF	Underestimated compared to the INECP, which forecasts a higher CF
Biomass	Almost equivalent production, share, CF and FLH	Underestimated compared to the INECP, which forecasts an improvement in the CF compared to the Baseline Scenario
Solar PV	Almost equivalent production, share, CF and FLH	Almost equivalent production, share, CF and FLH
CSP	Overestimated in the generated scenario	Underestimated in the generated scenario compared to the INECP, which models an improvement in the technology of the new power plants (leading to a higher CF)
Coal	Largely overestimated in the generated scenario, due to the accumulation of errors from the other technologies compared to the INECP (e.g. less nuclear, negative balance between export/import, others, etc.)	Coal is phased out in the Target Scenario
Natural Gas	INECP results are placed between the interconnected and island mode results	INECP results are almost equivalent to the interconnected
Nuclear	Slightly underestimated due to a lower CF in the generated Scenarios	Slightly underestimated due to a lower CF in the generated Scenarios compared to INECP (half capacity, but same CF between INECP Baseline and Target Scenario)
Others	Modelled by the INECP only (composed of municipal solid waste, waste cogeneration, petroleum product cogeneration plus biogas/geothermal/marine energy and renewables cogeneration), but equivalent to the Baseline Scenario	
Pumped Hydro Energy Storage	INECP capacity factor (11.1%) in between interconnected (underestimated: 5.9%) and island mode (overestimated: 22.8%), approximately twice the current average CF for Spanish PHES	INECP capacity factor (12.6%) in between interconnected (underestimated: 9.9%) and island mode (overestimated: 28.8%), almost three times the current average CF for Spanish PHES
Export	Highest export forecasted by the INECP (28.9 TWh) compared to the interconnected case study (18.2 TWh), lower utilisation of the interconnection line	Highest export forecasted by the INECP (48 TWh) compared to the interconnected case study (27.2 TWh). Export does not occur in island mode

	compared to Portugal. Export does not occur in island mode	
Import	INECP only; import does not occur in the generated Scenario since the system is self-sufficient	INECP only; import does not occur in the generated Scenario since the system is self-sufficient

7.3 Iberia: 2030 Target ScenariSo

The Iberia 2030 Target Scenario has been generated by aggregating the electricity generation systems of Portugal and Spain, following the methodology described below:

- **Demand**: cumulative demand computed using the TYNDP Sustainable Transition Scenario load profiles for Portugal and Spain (Table 18);
- **Wind and Solar**: weighted average normalized distribution computed, as shown in equation 17

$$\delta_{RES\_Iberia,k} = \frac{C_{PV\_PT} * \delta_{PV\_PT,k} + C_{PV\_ESP} * \delta_{PV\_ESP,k}}{C_{PV\_PT} + C_{PV\_ESP}} \quad (20)$$

- **Hydropower**: sum of the water supplies for Portugal and Spain; distribution normalized with the average precipitations on the two countries (see Table 12);
- **Capacities**: cumulative capacities as computed in Table 25, using the high-RES Scenario for Portugal and the Target Scenario for Spain.

Table 25 - Iberia 2030 Target Scenario: main parameters - Interconnected vs Island mode

		INTERCONNECTED				ISLAND MODE			
	Cap.	**Prod.**	**Share**	**CF**	**FLH**	**Prod.**	**Share**	**CF**	**FLH**
Hydro	32.8	47.1	12.7%	16.4%	1437	47.1	13.0%	16.4%	1436
Wind	59.5	132.1	35.5%	25.3%	2219	132.1	36.6%	25.3%	2219
Biomass	2.18	12.3	3.3%	64.3%	5633	12.3	3.4%	64.3%	5633
Solar PV	46.2	83.3	22.4%	20.6%	1802	83.3	23.1%	20.6%	1802
CSP	7.6	21.0	5.6%	31.5%	2761	21.0	5.8%	31.5%	2761
NG	35.3	53.2	14.3%	17.2%	1506	42.0	11.6%	13.6%	1190
Nuclear	3.2	23.5	6.3%	83.8%	7342	23.5	6.5%	83.8%	7342
Pumping	13.1	-19.6	-	17.1%	1501	-33.2	-	29.0%	2536
Battery	2.5	-0.97	-	4.4%	388	-1.36	-	6.2%	546
Export	8	-23.1	-	33.0%	2892	0.0	-	0.0%	0

CEEP	-	-6.72	-	-	-	-15.92	-	-	-
Unit	*GW*	*TWh*	*%*	*%*	*hrs*	*TWh*	*%*	*%*	*hrs*

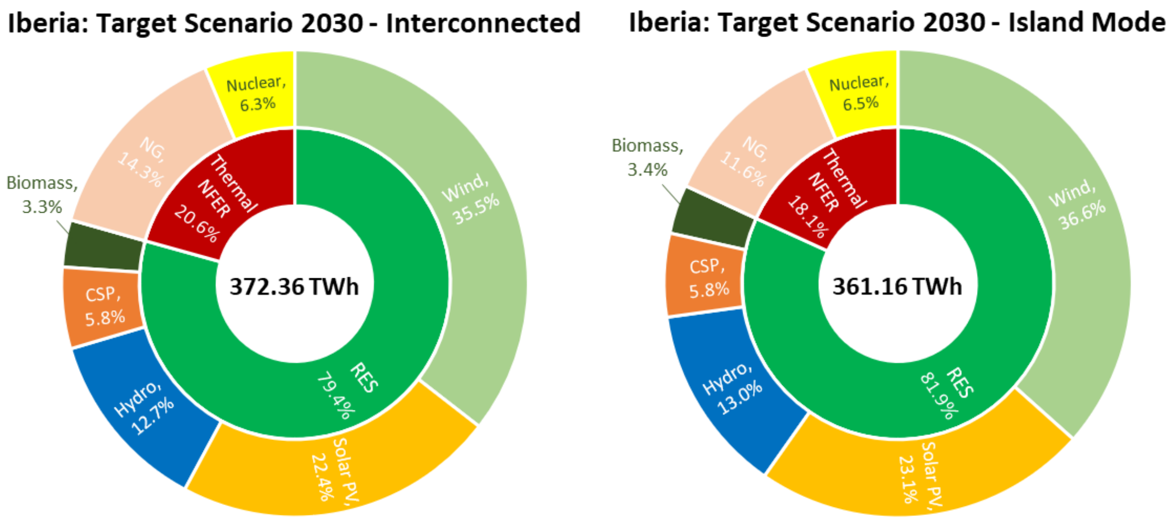


Figure 45 - Electricity production breakdown: Interconnected vs Island mode (Iberia 2030 Target Scenario)

7.3.1 Final comments

As it can be seen from the results obtained in the different Scenarios and with the generation systems planned by the two NECPs by 2030, the dispatch of all the electricity coming from variable renewable energy sources (wind and solar) will not always be possible, leading to critical excess of electricity production.

The main differences between interconnected and island mode can hereby be identified: the interconnected case study is characterized by an extremely optimistic electricity export, which occurs predominantly during daytime (peak of solar production), assuming constant and full interconnection capacity availability throughout the year; in island mode, PHES always operates when there is excess of electricity from variable RES, undergoing thousands cycles of pumping throughout the year and reaching a CF close to 30%. In this case, the water reservoirs are constantly refilled and the electricity excess is stored within the system, rather than exported. As a consequence, hydro substitutes NG for managing the grid stability, often operating together with the pumps, which explains the higher RES share achieved and the lower CF of NG in island mode. Moreover, island mode is still characterized by a more significative CEEP which must be curtailed to keep the energy balance, given the unavailability of the interconnection lines.

With regards to the Iberia setting, in order to analyse the effect of the aggregation, it is necessary to define two relative parameters for the excess and critical excess electricity production, which can be obtained by dividing the EEP_{adj} and $CEEP_{adj\_isl}$ (under island mode) by the total variable RES production $El_{PV} + El_{wind}$:

$$EEP_{adj}[\%] = \frac{EPP * (1 - f_{grid})}{El_{PV} + El_{wind}} = \frac{EEP_{adj}}{El_{PV} + El_{wind}} \tag{21}$$

$$CEEP_{adj\_isl}[\%] = \frac{CEEP * (1 - f_{grid})}{El_{PV} + El_{wind}} = \frac{CEEP_{adj}}{El_{PV} + El_{wind}} \quad (22)$$

With these parameters, one of the theoretical benefits of the aggregation between the two Iberian countries can be noticed in Table 26 with the decrease of the $CEEP_{adj\_isl}$ in the Iberia setting (5.2%), compared to Spain only (5.3%) or to the cumulative $CEEP_{adj\_isl}$ for Spain Target Scenario and Portugal High-RES Scenario (6.3%). However, the aggregation would theoretically mean assuming unlimited interconnection capacity available between Portugal and Spain, which obviously does not reflect the reality. A higher interconnection capacity favours the integration of renewable energy in neighbouring Member States, especially the ones located in the peripheral part of the European Union.

Table 26 - Electricity excess production (2030 Target Scenario)

	PT LOW-RES	PT HIGH-RES	SPAIN	IBERIA	*Unit*
$El_{PV,wind}$	36.1	39.8	178.1	215.4	*TWh*
EEP	10.86	15.1	38.7	50.4	*TWh*
$CEEP_{isl}$	1.97	6.16	13.39	15.92	*TWh*
EEP_{adj}	7.6	10.57	27.1	35.28	*TWh*
$EEP_{adj}[\%]$	21.1%	26.6%	15.2%	16.4%	-
$CEEP_{isl\_adj}$	1.38	4.3	9.37	11.14	*TWh*
$CEEP_{isl\_adj}[\%]$	3.8%	10.8%	5.3%	5.2%	-

Moreover, it can be seen how Portugal is characterized by a higher $EEP_{adj}[\%]$, which means that between 21.1% and 26.6% of the total RES electricity (according to the Scenario) must be removed from the system through curtailment or by pumping/exporting, so the Portuguese system will overproduce more electricity compared to Spain. Under the Low-RES Scenario, pumped hydro is able to manage the extra electricity excess (as demonstrated by the low $CEEP_{isl\_adj}[\%]$), which however increases sharply in the high-RES Scenario to 10.8%.

8 Conclusion

The growing complexity of energy systems and the need for long-term planning on the European and national level justifies the development of energy models, in order to support the governments in their decision making and strategic choices in the energy sector. Designing public policies that cope reliable systems, compatible with GHG mitigation goals and able to accommodate an increasing share of electricity from variable renewable energy sources is of crucial importance.

The National Energy and Climate Plans are not just a policy tool to define a pathway to 2030 goals, but also to promote collaborations between different countries and to ensure transparency with the European Commission, that can monitor and guide all the EU28 towards the cumulative accomplishment of the overall energy targets.

Furthermore, this report provided a model-derived simulation of different possible future electricity mixes under certain conditions, focusing on the technical feasibility rather than the market economic. In fact, today's markets are primarily designed for dispatchable plants, whereas 100% renewable energy systems will depend on very high levels of non-dispatchable renewable energy, which are expected to radically influence the current market structure and yet difficult to model with high accuracy. With regards to the modelling, even if the EnergyPLAN model is not as detailed as the TIMES_PT and TIMES-SINERGIA models, coherent and similar results were obtained when analysing the Scenarios generated under different conditions, which were demonstrated to be all technically feasible.

However, the electricity excess production phenomenon have been demonstrated to be significant in the Iberian Peninsula: with an expected interconnection level of only 4.3% with the European continent (Morocco not considered) by 2030, the high penetration for renewables will be tackled prevalently through pumping, storing or curtailment. In particular, by modelling Iberia in island mode, an extremely high pumped hydro capacity factor is obtained (29%), which represents almost three times the current Iberian PHES capacity factor. Hence, an investigation of the maximum potential of pumping in both countries, together with the electricity exchanges between Member States is necessary to establish the future ratio between electricity pumped, stored, exported or curtailed and how the electricity excess will be distributed among these options.

Portugal is expected to achieve a high share of hydropower capacity in its generation system by 2030, between 28% (high-RES) and 31% (low-RES), while the Spanish share will stabilize around 15% in Target Scenario. The higher share of hydropower compared to other grid stabilising units makes Portugal more dependent on wet and dry years compared to Spain, fundamental for keeping grid stability. Wind will become the predominant source of electricity in the Iberian Peninsula, expecting around 35% of the final electricity produced in Iberia by 2030 coming from this renewable source. Solar PV will be characterized by a huge deployment of new installations, with more than +40 GW of new solar capacity in the Iberia only, consisting of 770% of relative growth compared to 2015 installed capacity.

With regards to the NECPs, the Spanish "Plan Nacional Integrado de Energìa y Clima" (INECP) is more detailed and well-structured compared to the Portuguese "Plano Nacional Energia e Clima" (PNEC), which lacks several information (e.g. flow of investments, expected electricity generation, etc.). Finally, the consultation of other Member States' National Energy and Climate Plans is strongly advised to improve the quality and the consistency of the national NECP.

9 Bibliography

APA. (2019). *Portuguese National Inventory Report on Greenhouse Gases, 1990-2017.*

Artelys. (2017). *METIS Power System Module.* Brussels. Retrieved from https://ec.europa.eu/energy/en/data-analysis/energy-modelling/metis

Basque Center for Climate Change. (2019). *Borrador del Plan Nacional Integrado de Energía y Clima 2021-2030.*

Bellini, E. (2019, August 09). *Winners, projects, prices of Portugal's record PV auction.* Retrieved from PV Magazine: https://www.pv-magazine.com/2019/08/09/winners-projects-prices-of-portugals-record-pv-auction/

CEER. (2019). *Regulatory Aspects of Self-consumption and Energy Communities.* Brussels.

Connolly, D., Lund, H., & Mathiesen, B. (2013). *Smart Energy Systems: Holistic and Integrated Energy Systems for the era of 100% Renewable Energy.* Aalborg University.

DGEG - Installed capacity. (2019). *Potência Instalada nas Centrais Produtoras de Energia Elétrica (2008-2017).*

DGEG - Key Energy Statistics. (2019). *Key Energy Statistics 2017.*

Draft INECP. (2019). *Borrador del Plan Nacional Integrado de Energía y Clima.* Madrid.

Draft PNEC. (2018). *Plano Nacional Integrado Energia e Clima 2021-2030.*

Eco News. (2018, August 7). *Why are electricity bills so high in Portugal? Taxation is the answer.* Retrieved from https://econews.pt/2018/08/07/why-are-electricity-bills-so-high-in-portugal-taxation-is-the-answer/

EDP. (2018). *Iberian Data 2017.* Energy Planning Department.

EDP Distribuição. (2018). *Relatório da qualidade do serviço.*

EDP Produção. (2018). *Energy Sector in Portugal.* Retrieved from https://portugal.edp.com/en/energy-sector-in-portugal/generation-and-supply

ENTSO-E: 2030 Loads. (2018). *Maps & Data*. Retrieved from TYNDP 2018: https://tyndp.entsoe.eu/maps-data/

ENTSO-E: Factsheet. (2018). *Statistical Factsheet 2017.*

ENTSO-E: TYNDP. (2018). *TYNDP 2018 Scenario Report.*

ENTSO-E: Winter Outlook. (2017). *Winter Outlook 2016/17.*

ERSE - PRE. (2017). *Produção em Regime Especial.* Retrieved from http://www.erse.pt/pt/desempenhoambiental/rotulagemenergetica/pre/Paginas/default.aspx

ERSE. (2016). *Regime de atribuição de incentivos à garantia de potência no âmbito do sistema elétrico nacional – Relatorio de avaliação técnica .*

ERSE. (2018). *Annual Report on the Electricity and Natural Gas Markets in 2017.* Lisbon.

ERSE. (2018). *Generation in special regimes in Portugal in 2017.* Retrieved from http://www.erse.pt/pt/desempenhoambiental/prodregesp/2017/Paginas/2017.aspx

EUFORES. (2019). *The impact of the EU's clean energy package on Hungary's energy transition.* Budapest.

Eurelectric. (2011). *Hydro in Europe: powering renewables.* Brussels.

European Commission - CEP. (2019). Retrieved from Clean Energy for all Europeans: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

European Commission - CEP: Buildings. (2019). *Factsheet - The energy performance of buildings directive.* Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/buildings_performance_factsheet.pdf

European Commission - CEP: Governance. (2018). *Governance of the Energy Union and Climate Action Rules.*

European Commission - Energy Datasheet. (2019, 07 17). *EU energy in figures: statistical pocketbook.* Retrieved from https://ec.europa.eu/energy/en/data-analysis/energy-statistical-pocketbook

European Commission - NECPs. (2019, 08 01). *National Energy and Climate Plans*. Retrieved from https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/governance-energy-union/national-energy-climate-plans

European Commission - NECPs Recommendation. (2019). *Commission Recommendation on the draft integrated National Energy and Climate Plan covering the period 2021-2030.* Brussels.

European Commission - Reference Scenario. (2016). *EU Reference Scenario 2016.*

European Commission. (2008). *European Energy and Transport: trends to 2030 - Update 2007.*

European Commission. (2016). *Impact Assessment on Energy Efficiency Directive.* Brussels.

European Commission. (2017). *EU 2020 reporting.* Retrieved from https://ec.europa.eu/clima/policies/strategies/progress/reporting_en#tab-0-0

European Commission. (2018). *Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources.* Brussels.

European Commission. (2019). *Communication assessing the 28 draft NECPs.* Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/recommondation_en.pdf

European Commission. (2019, January). *Factsheet - The revised renewable energy directive.* Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/directive_renewable_factsheet.pdf

European Environment Agency. (2018). *Trends and projections in Europe 2018.*

European Parliament - Electricity Market. (2019). *Briefing - Internal market for electricity.*

European Parliament - Interconnection. (2017). *Communication on achieving a 15% electricity interconnection target.* Retrieved from Legislative Train Schedule: http://www.europarl.europa.eu/legislative-train/theme-resilient-energy-union-with-a-climate-change-policy/file-communication-on-achieving-a-15-electricity-interconnection-target/10-2016

European Parliament - Renewable Energy. (2019, January 15). *Briefing - Promoting renewable energy sources in the EU after 2020.* Retrieved from http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/599278/EPRS_BRI(2017)599278_EN.pdf

Eurostat - Energy Balance. (2019, September 03). *Energy balance flow for European Union (28 countries).* Retrieved from https://ec.europa.eu/eurostat/cache/sankey/sankey.html

Eurostat - Renewables. (2019, January). *Renewable Energy Statistics.* Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics#Renewable_energy_produced_in_the_EU_increased_by_two_thirds_in_2007-2017

Eurostat. (2019, May). *Electricity Price Statistics.* Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

FS-UNEP. (2018). *Global Trends in Renewable Energy Investments 2018.*

GEO. (2019). *Average monthly rainfall in Portugal.* Retrieved from Statista: https://www.statista.com/statistics/802732/average-monthly-rainfall-portugal/

Global Legal Insights. (2019). *Energy 2019 - Portugal.* Retrieved from https://www.globallegalinsights.com/practice-areas/energy-laws-and-regulations/portugal

Gobierno de España. (2017). *La Energía en España 2016.* Madrid.

Gouveia, J. P., Dias, L., Fortes, P., & Seixas, J. (2012). *TIMES_PT: Integrated Energy System Modeling.* Lisbon: CENSE - Center for Environmental and Sustainability Research, Faculdade de Ciências e Tecnologia.

IEA. (2015). *Energy Policies of IEA Countries - Spain.*

IEA. (2016). *Energy Policies of IEA countries - Portugal.*

IRENA - CSP. (2012). *Renewable Energy Technology: cost analysis series - CSP.*

ISIS – Institute of Studies for the Integration of Systems. (2009). *NEEDS - New Energy Externalities Developments for Sustainability: final activity report.*

Kougias, I., & Szabó, S. (2017). *Pumped hydroelectric storage utilization assessment: Forerunner of renewable energy integration or Trojan horse?* Ispra, Italy: European Commission - Joint Research Center. Retrieved from https://www.sciencedirect.com/science/article/pii/S0360544217314822

Letcher, T. M. (2016). *Storing Energy: with Special Reference to Renewable Energy Sources.* Elsevier Science.

Loulou, R., Remne, U., Kanudia, A., Lehtila, A., & Goldstein, G. (2016). *Documentation for the TIMES Model - Part I.*

Lund & Mathienses. (2006). *Ingeniørforeningens Energiplan 2030.*

Lund, H., & Thellufsen, J. Z. (2018). *Advanced Energy Systems Analysis Computer Model - Documentation Version 14.* Aalborg University.

Mendes, A. (2018, January 24). *Produção das barragens da EDP afundou 55% em 2017 devido à seca.* Retrieved from Jornal de Negocios: https://www.jornaldenegocios.pt/empresas/energia/detalhe/producao-das-barragens-da-edp-afundou-55-em-2017-devido-a-seca

MIBEL. (2019). *Iberian Electricity Market.* Retrieved from https://www.mibel.com/en/home_en/

Ministerio de Medio Ambiente. (1997). *Average precipitation for Spain as a whole 1930-1996.* Retrieved from http://www.iberianature.com/material/Spain_climate/Rainfall_Spain.htm

NREL. (2019). *Concentrating Solar Power Projects.* Retrieved from SolarPACES: https://solarpaces.nrel.gov/

OMEL. (2017, January 01). *Spot Market Prices.* Retrieved from REN - Sistema de Informação de Mercados de Energia: http://www.mercado.ren.pt/EN/Electr/MarketInfo/MarketResults/OMIE/Pages/Prices.aspx

Pina, A. (2019, June 28). Personal communication on PNEC. (D. Neves, & F. Barbieri, Interviewers)

Pinho, P. (2019, June 18). Shaping EU's Energy Future: making NECPs come to life.

PNEC - Consulta Pública. (2019). *Plano Nacional Energia e Clima - Consulta Pública.*

PNEC - Sessão de apresentação. (2019, January 28). Sessão de apresentação do Plano Nacional Integrado Energia-Clima. Lisbon.

Pylon Network. (2018, May 23). *The actors of the Spanish energy system.* Retrieved from https://medium.com/@pylonnetwork/the-actors-of-the-spanish-energy-system-5331fb04a6a

RED - Generation. (2019). *Red Eléctrica de España*. Retrieved from https://www.ree.es/en/datos/generation

RED - Report. (2019). *The Spanish Electricity System.*

REE. (2019). *About REE*. Retrieved from https://www.ree.es/en/about-us

REN - Estatística Anual. (2019). *Electricidade: Estatística Anual 2009-2018.* Lisbon.

REN - Market Information. (2017). *Market information.* Retrieved from Sistema de Informação de Mercados de Energia: http://www.mercado.ren.pt/EN/ELECTR/MARKETINFO/Pages/default.aspx

REN. (2017). *Market Information - Actual Generation.* Retrieved from Sistema de Informação de Mercados de Energia: http://www.mercado.ren.pt/EN/Electr/MarketInfo/Gen/Pages/Actual.aspx

REN. (2018). *Actual Total Load*. Retrieved from Sistema de Informação de Mercados de Energia: http://www.mercado.ren.pt/EN/Electr/MarketInfo/Load/Pages/Actual.aspx

REN. (2019). *About REN*. Retrieved from https://www.ren.pt/en-GB/quem_somos/

REN. (2019). *Estatística Diária - SEN.* Retrieved from Electricidade - Centro de informacão: http://www.centrodeinformacao.ren.pt/PT/InformacaoExploracao/Paginas/EstatisticaDiariaHidraulica.aspx

Ruiz, J. I., Benito, M. J., & Menéndez, U. (2018, August 01). *Electricity regulation in Spain: overview.* Retrieved from Thomson Reuters - Practical Law: https://uk.practicallaw.thomsonreuters.com/4-529-8116?transitionType=Default&contextData=(sc.Default)&firstPage=true&bhcp=1

Santana, J., & Castro, R. (2016). *Economics and Energy Markets.* Lisbon.

Schneidewindt, H. (2019, April 09). *Spain takes the lead in joint renewables self-consumption*. Retrieved from Energy Democracy: https://energy-democracy.org/spain-takes-the-lead-in-joint-renewables-self-consumption/

TESLA. (2019). *Powerpack - Commercial & Utility*. Retrieved from TESLA: https://www.tesla.com/powerpack

Willuhn, M. (2019, July 12). *Portuguese 1.4 GW solar tender with €0.045/kWh ceiling receives 10 GW of applications.* Retrieved from PV Magazine: https://www.pv-magazine.com/2019/07/12/portuguese-1-4-gw-solar-tender-with-e0-045-kwh-ceiling-receives-10-gw-of-applications/

10 Annex

10.1 RES Accounting

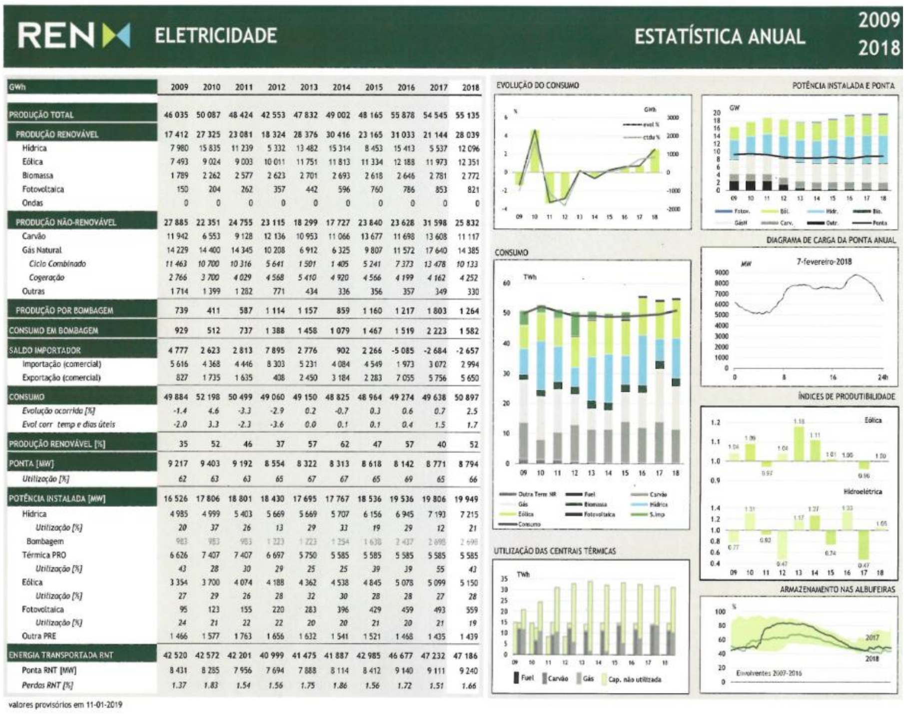
Table 27 provides the distinction between what has to be accounted or excluded in the computation of the gross final energy consumption from RES, as established by the Renewable Energy Directive.

Table 27 - Gross final energy consumption from RES to be accounted

ELECTRICITY	HEATING AND COOLING	TRANSPORT
To be accounted for ☑ • Hydro and Wind after normalisation as per rules in Annex II of the Directive • Self-consumed electricity within communities • Fraction of renewable, based on energy source in multi-fuel plants **To be excluded ☒** • Electricity from PHES • Electricity converted to synthetic fuels in transport	**To be accounted for ☑** • District Heating and Cooling from RES • Self-Consumption from renewables • Ambient and geothermal energy via heat pumps as per Annex VII • In multi-fuel plants, only part used for heating and cooling **To be excluded ☒** • Energy saved in Passive houses	**To be accounted for ☑** • Advanced Biofuels as per energy values • Synthetic Biofuels including Power to gas from renewables • Synthetic Biofuels including Power to gas

10.2 REN Yearly Statistics: 2009-2018

Figure 46 provides a screenshot of the REN Yearly Statistics covering ten years (from 2008 until 2018).



GWh	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
PRODUÇÃO TOTAL	46 035	50 087	48 424	42 553	47 832	49 002	48 165	55 878	54 545	55 135
PRODUÇÃO RENOVÁVEL	17 412	27 325	23 081	18 324	28 376	30 416	23 165	31 033	21 144	28 039
Hídrica	7 980	15 835	11 239	5 332	13 482	15 314	8 453	15 413	5 537	12 096
Eólica	7 493	9 024	9 003	10 011	11 751	11 813	11 334	12 188	11 973	12 351
Biomassa	1 789	2 262	2 577	2 623	2 701	2 693	2 618	2 646	2 781	2 772
Fotovoltaica	150	204	262	357	442	596	760	786	853	821
Ondas	0	0	0	0	0	0	0	0	0	0
PRODUÇÃO NÃO-RENOVÁVEL	27 885	22 351	24 755	23 115	18 299	17 727	23 840	23 628	31 598	25 832
Carvão	11 942	6 553	9 128	12 136	10 953	11 066	13 677	11 698	13 608	11 117
Gás Natural	14 229	14 400	14 345	10 208	6 912	6 325	9 807	11 572	17 640	14 385
Ciclo Combinado	*11 463*	*10 700*	*10 316*	*5 641*	*1 501*	*1 405*	*5 241*	*7 373*	*13 478*	*10 133*
Cogeração	*2 766*	*3 700*	*4 029*	*4 568*	*5 410*	*4 920*	*4 566*	*4 199*	*4 162*	*4 252*
Outras	1 714	1 399	1 282	771	434	336	356	357	349	330
PRODUÇÃO POR BOMBAGEM	739	411	587	1 114	1 157	859	1 160	1 217	1 803	1 264
CONSUMO EM BOMBAGEM	929	512	737	1 388	1 458	1 079	1 467	1 519	2 223	1 582
SALDO IMPORTADOR	4 777	2 623	2 813	7 895	2 776	902	2 266	-5 085	-2 684	-2 657
Importação (comercial)	5 616	4 368	4 446	8 303	5 231	4 084	4 549	1 973	3 072	2 994
Exportação (comercial)	827	1 735	1 635	408	2 450	3 184	2 283	7 055	5 756	5 650
CONSUMO	49 884	52 198	50 499	49 060	49 150	48 825	48 964	49 274	49 638	50 897
Evolução ocorrida [%]	*-1.4*	*4.6*	*-3.3*	*-2.9*	*0.2*	*-0.7*	*0.3*	*0.6*	*0.7*	*2.5*
Evol corr temp e dias úteis	*-2.0*	*3.3*	*-2.3*	*-3.6*	*0.0*	*0.1*	*0.1*	*0.4*	*1.5*	*1.7*
PRODUÇÃO RENOVÁVEL [%]	35	52	46	37	57	62	47	57	40	52
PONTA [MW]	9 217	9 403	9 192	8 554	8 322	8 313	8 618	8 142	8 771	8 794
Utilização [%]	*62*	*63*	*63*	*65*	*67*	*67*	*65*	*69*	*65*	*66*
POTÊNCIA INSTALADA [MW]	16 526	17 806	18 801	18 430	17 695	17 767	18 536	19 536	19 806	19 949
Hídrica	4 985	4 999	5 403	5 669	5 669	5 707	6 156	6 945	7 193	7 215
Utilização [%]	*20*	*37*	*26*	*13*	*29*	*33*	*19*	*29*	*12*	*21*
Bombagem	983	983	983	1 223	1 223	1 254	1 638	2 437	2 698	2 698
Térmica PRO	6 626	7 407	7 407	6 697	5 750	5 585	5 585	5 585	5 585	5 585
Utilização [%]	*43*	*28*	*30*	*29*	*25*	*25*	*39*	*39*	*55*	*43*
Eólica	3 354	3 700	4 074	4 188	4 362	4 538	4 845	5 078	5 099	5 150
Utilização [%]	*27*	*29*	*26*	*28*	*32*	*30*	*28*	*28*	*27*	*28*
Fotovoltaica	95	123	155	220	283	396	429	459	493	559
Utilização [%]	*24*	*21*	*22*	*22*	*20*	*20*	*21*	*20*	*21*	*19*
Outra PRE	1 466	1 577	1 763	1 656	1 632	1 541	1 521	1 468	1 435	1 439
ENERGIA TRANSPORTADA RNT	42 520	42 572	42 201	40 999	41 475	41 887	42 985	46 677	47 232	47 186
Ponta RNT [MW]	8 431	8 285	7 956	7 694	7 888	8 114	8 412	9 140	9 111	9 240
Perdas RNT [%]	*1.37*	*1.83*	*1.54*	*1.56*	*1.75*	*1.86*	*1.56*	*1.72*	*1.51*	*1.66*

valores provisórios em 11-01-2019

Figure 46 – Electricity: Yearly Statistics 2009-2018. Source: (REN - Estatística Anual, 2019)

10.3 Portugal 2017: Market Economic Analysis

For the market economic simulation, the external electricity market price is required as additional input, which in this case is equivalent to the Spanish Spot Market Price, which determines one electricity price for Portugal and one electricity price for Spain. As example, the daily and intraday spot market prices are included, divided in seven different sessions. Since the EnergyPLAN model requires a hourly price distribution (in €/MWh) as input for the external market price, only the Session 0 will be considered, as highlighted in Figure 47. Additionally, it is important to mention that no taxes are included in the model, which usually affects the market prices and hence import/export.

HOUR	Market Sessions															
			Session 1		Session 2		Session 3		Session 4		Session 5		Session 6		Session 7	
	PT	ES	PT	ES	PT	ES	PT	ES	PT	ES	PT	ES	PT	ES	PT	ES
1	58,82	58,82	57,82	57,82	58,00	58,00										
2	58,23	58,23	57,57	57,57	58,23	58,23										
3	51,95	51,95	48,95	48,95	51,95	51,95										
4	47,27	47,27	48,14	48,14	50,27	50,27										
5	46,90	**45,49**	47,50	47,50	49,00	49,00	50,50	50,50								
6	46,60	**44,50**	46,60	46,60	46,60	46,60	49,39	49,39								
7	46,25	**44,50**	46,25	46,25	49,99	**46,50**	49,39	49,39								
8	46,10	**44,72**	46,72	46,72	47,72	47,72	50,00	50,00	48,10	48,10						
9	46,10	**44,22**	46,10	46,10	47,05	47,05	47,88	47,88	48,00	48,00						
10	45,13	45,13	47,00	47,00	46,06	46,06	47,88	47,88	47,86	47,86						
11	46,23	46,23	48,14	48,14	49,39	49,39	50,40	50,40	49,43	49,43						
12	47,91	47,91	49,00	49,00	49,91	49,91	51,33	51,33	51,23	51,23	54,39	54,39				
13	49,57	49,57	50,29	50,29	51,56	51,56	52,43	52,43	52,33	52,33	53,25	53,25				
14	48,69	48,69	49,69	49,69	51,18	51,18	52,14	52,14	52,04	52,04	52,29	52,29				
15	47,20	47,20	48,50	48,50	50,17	50,17	51,83	51,83	51,73	51,73	54,33	54,33				
16	46,51	46,51	47,91	47,91	48,88	48,88	49,00	49,00	49,00	49,00	48,00	48,00	50,00	50,00		
17	46,52	46,52	47,86	47,86	48,88	48,88	50,00	50,00	50,00	50,00	51,50	51,50	50,01	50,01		
18	51,59	51,59	50,59	50,59	54,22	54,22	55,41	55,41	55,59	55,59	57,30	57,30	57,00	57,00		
19	59,07	59,07	58,88	58,88	59,50	59,50	62,50	62,50	61,21	61,21	60,00	60,00	62,90	62,90		
20	62,10	62,10	61,10	61,10	62,80	62,80	64,80	64,80	62,10	62,10	62,00	62,00	63,64	63,64		
21	64,20	64,20	62,45	62,45	63,28	63,28	64,84	64,84	64,19	64,19	59,69	59,69	64,00	64,00		
22	60,69	60,69	60,86	60,86	61,01	61,01	61,00	61,00	61,00	61,00	59,00	59,00	62,00	62,00	64,00	64,00
23	59,07	59,07	60,07	60,07	59,07	59,07	58,07	58,07	58,57	58,57	57,00	57,00	59,07	59,07	59,92	59,92
24	52,00	52,00	52,66	52,66	53,00	53,00	51,82	51,82	51,90	51,90	52,00	52,00	52,00	52,00	49,00	49,00

Units: €/MWh   PT-Portugal; ES-Spain   Source: OMEL

Figure 47 - Sport Market Price of the January 1st, 2017 Market Session. Source: (OMEL, 2017)

Additionally, two other parameters define the external market response to import/export, namely:

- f_{elast} : price elasticity factor [in €/MWh/MW, which influences the market price under the economic simulation strategy and in the calculation of income from exchange. This value was set equal to 0.015 €/MWh/MW, as suggested by the developers (Lund & Mathienses, 2006);
- p_o : basic price level for price elasticity [in €/MWh], which the literature suggests to be between 40%-50% of the input price[42] (Lund & Mathienses, 2006).

Hence, the resulting price is computed as follow during the optimisation:

$$p_m = p_i + \left(^{p_i}/_{p_o}\right) * \ f_{elast} * d_{imp/exp} \tag{23}$$

- p_m : final resulting hourly market price [in €/MWh];
- p_i : input price [in €/MWh];

[42] For the modelling, the basic price level for price elasticity will be always set to 50% of the resulting average price after the addition factor

- $d_{imp/exp}$: trade on the market [in MW], where import is calculated as positive and export is negative, resulting in an increase in the market price in the case of import and a decrease in the case of export.

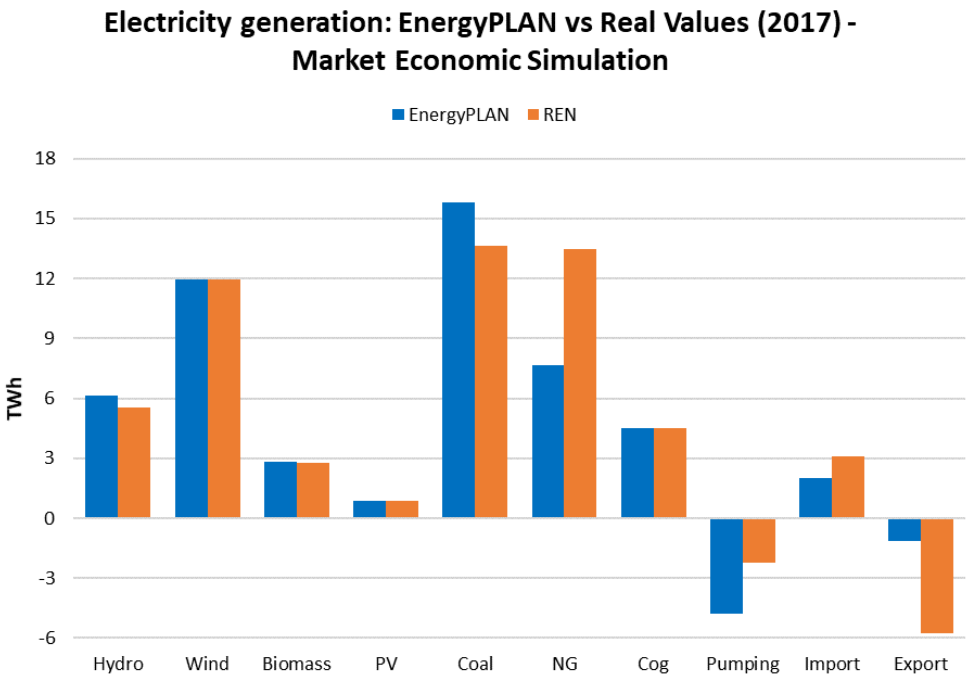


Figure 48 - Market economic analysis – Electricity production: comparison between EnergyPLAN and REN vales (Portugal 2017)

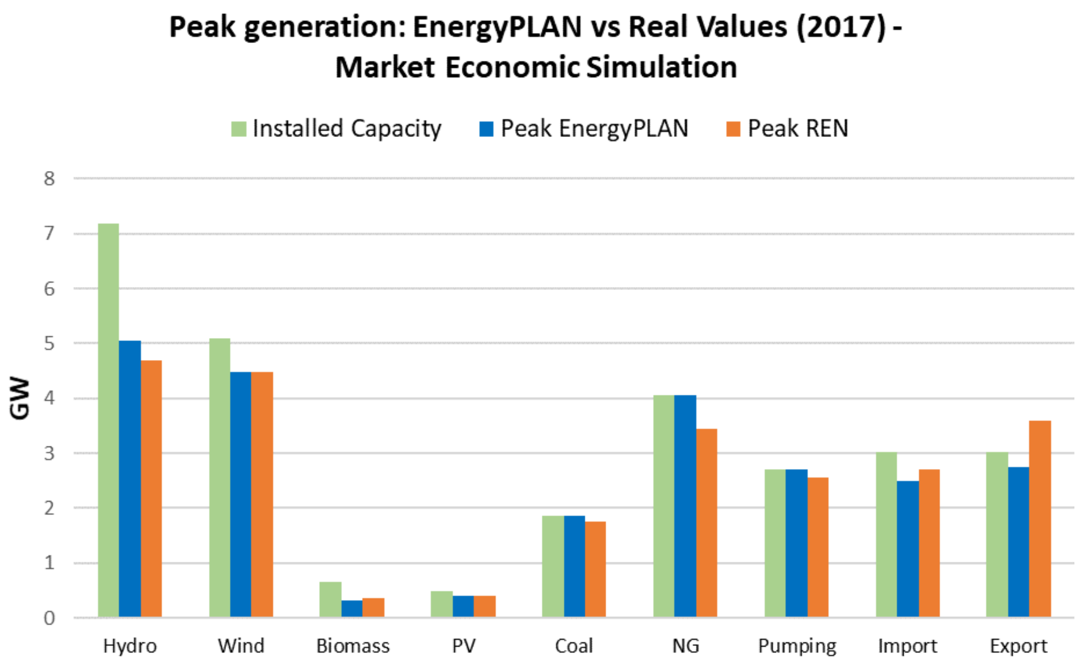


Figure 49 - Market economic analysis – Peak generation: comparison between EnergyPLAN and REN vales (Portugal 2017)

10.4 Spanish Hydropower Statistics

As done for the Portuguese case, Spanish hydropower statistics are shown in Table 28, together with the computation of the average capacity factor.

Table 28 – Spanish Hydropower statistics. Adapted from: (RED - Generation, 2019)

	UNIT	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	AVG
Production	TWh	26.19	41.83	30.44	20.65	37.38	39.18	28.38	36.11	18.45	34.11	-
Water Inp.	TWh	29.10	46.48	33.82	22.95	41.54	43.53	31.53	40.12	20.50	37.90	-
Capacity	GW	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03	17.03	-
Hours	Hrs	1538	2456	1787	1213	2195	2301	1666	2120	1083	2003	**1836**
CF	-	17.6%	28.0%	20.4%	13.8%	25.1%	26.3%	19.0%	24.2%	12.4%	22.9%	**21.0%**

10.5 EnergyPLAN: modelling outcomes

The following table depict an overview of the modelling outcomes for all the scenarios generation for Portugal, Spain and Iberia under both interconnected and island mode.

Table 29 - Portugal 2030 Low-RES Scenario - Interconnected

Portugal 2030 Low-RES Scenario				Grid stab		30%	i	6%	RES	90.4%	Tot	62.69 TWh		**Interconnected**			
	Electr. Demand	Wind Electr.	PV Electr.	Biomass Electr.	CSP2 Electr.	CSP2 Storage	CSP2 loss	Hydro Electr.	Hydro pump	Storage TWh	Hydro Wat-Sup	NG Electr.	Stabil. Load	Import Electr.	Export Electr.	CEEP Electr.	EEP Electr.
Annual Average [MW]	6083	2505	1603	420	91	416	2	2004	199	1.679	2079	686	157	11	1038	23	1015
Annual Maximum [MW]	10362	7813	6496	420	300	2239	395	4065	3578	3.114	3465	2800	331	2576	9244	5644	3600
Annual Minimum [MW]	3680	10	0	420	0	0	0	440	0	0.000	242	0	100	0	0	0	0
Sum [TWh/year] - 365d	53.33	21.97	14.06	3.68	0.80	3.66	0.02	17.56	1.75	-	18.18	6.02	-	0.09482	9.11	0.20	8.91
Monthly Average Values [MW]																	
January	6787	2837	1099	420	7	1892	10	2350	104	1.982	3465	830	166	49	701	3	698
February	6640	3486	1111	420	14	2043	10	2289	186	2.685	3329	663	150	10	1166	5	1161
March	6135	3179	1527	420	76	744	5	2171	363	2.989	2172	505	145	1	1380	77	1303
April	5728	2401	1898	420	121	54	0	2140	397	3.040	2120	523	158	0	1379	75	1304
May	5804	2039	1857	420	118	51	0	2154	223	2.923	1669	544	166	0	1104	31	1073
June	5714	2147	2029	420	130	47	0	2053	323	2.393	1127	398	153	0	1141	26	1115
July	6142	2175	2070	420	132	61	0	2040	107	1.362	317	348	145	0	937	1	936
August	5630	2055	2014	420	129	64	0	931	188	0.481	269	1424	152	9	1163	4	1158
September	5817	2129	1873	420	120	46	0	1413	170	0.144	1088	1099	156	9	1076	34	1042
October	5821	1839	1490	420	95	25	0	2168	128	0.109	2658	659	178	3	726	12	714
November	6267	2550	1274	420	81	18	0	2184	90	0.690	3362	648	163	25	824	9	815
December	6527	3261	984	420	62	6	0	2170	109	1.406	3431	592	150	24	878	0	878

Table 30 - Portugal 2030 Low-RES Scenario – Island Mode

Portugal 2030 Low-RES Scenario				Grid stab		30%	i	6%	RES	99.1%	Tot	57.06 TWh		**Island Mode**			
	Electr. Demand	Wind Electr.	PV Electr.	Biomass Electr.	CSP2 Electr.	CSP2 Storage	CSP2 loss	Hydro Electr.	Hydro pump	Storage TWh	Hydro Wat-Sup	NG Electr.	Stabil. Load	Import Electr.	Export Electr.	CEEP Electr.	EEP Electr.
Annual Average [MW]	6083	2505	1603	420	91	416	2	2640	1012	1.806	2079	61	157	1	225	225	0
Annual Maximum [MW]	10362	7813	6496	420	300	2239	395	8405	3578	3.192	3465	2800	331	1839	9244	9244	0
Annual Minimum [MW]	3680	10	0	420	0	0	0	781	0	0.000	242	0	100	0	0	0	0
Sum [TWh/year] - 365d	53.33	21.97	14.06	3.68	0.80	3.66	0.02	23.13	8.88	-	18.18	0.54	-	0.00635	1.97	1.97	0.00
Monthly Average Values [MW]																	
January	6787	2837	1099	420	7	1892	10	3170	696	1.914	3465	58	166	0	108	108	0
February	6640	3486	1111	420	14	2043	10	2919	1158	2.553	3329	43	150	0	194	194	0
March	6135	3179	1527	420	76	744	5	2645	1298	2.930	2172	32	145	0	445	445	0
April	5728	2401	1898	420	121	54	0	2629	1299	3.132	2120	33	158	0	477	477	0
May	5804	2039	1857	420	118	51	0	2664	1070	3.100	1669	35	166	0	258	258	0
June	5714	2147	2029	420	130	47	0	2426	1112	2.714	1127	25	153	0	352	352	0
July	6142	2175	2070	420	132	61	0	2366	933	1.881	317	22	145	0	110	110	0
August	5630	2055	2014	420	129	64	0	2272	1156	1.021	269	91	152	0	195	195	0
September	5817	2129	1873	420	120	46	0	2375	1040	0.302	1088	138	156	8	206	206	0
October	5821	1839	1490	420	95	25	0	2658	712	0.078	2658	172	178	1	142	142	0
November	6267	2550	1274	420	81	18	0	2814	813	0.756	3362	43	163	0	101	101	0
December	6527	3261	984	420	62	6	0	2747	876	1.331	3431	39	150	0	111	111	0

Table 31 - Spain 2030 Baseline Scenario – Interconnected

Spanish 2030 Baseline Scenario				Grid stab		50%	i	6%	RES	52.2%	Tot	305.36 TWh		Interconnected					
	Electr. Demand	Wind Electr.	PV Electr.	Biomass Electr.	CSP2 Electr.	CSP2 Storage	CSP2 loss	Hydro Electr.	Hydro pump	Storage TWh	Hydro Wat-Sup	Coal Electr.	NG Electr.	Nuclear Electr.	Stabil. Load	Import Electr.	Export Electr.	CEEP Electr.	EEEP Electr.
Annual Average [MW]	32493	9612	3782	565	711	3675	23	3796	356	9.121	3901	4391	6063	6204	126	0	2275	201	2075
Annual Maximum [MW]	46595	26776	15323	565	2300	17164	7256	3970	6000	11.201	5449	4500	32100	6951	200	94	31789	20189	11600
Annual Minimum [MW]	20420	0	0	565	0	0	0	3438	0	6.367	1435	0	0	0	100	0	0	0	0
Sum [TWh/year] - 365d	284.75	84.34	33.16	4.95	6.24	-	0.20	33.25	3.12	-	34.15	38.46	53.12	54.33	-	0.00	19.99	1.76	18.22
Monthly Average Values [MW]																			
January	34712	11470	2592	565	177	12839	70	3821	312	9.582	4811	4415	7216	6924	126	0	2157	228	1929
February	35254	12729	2621	565	234	14149	76	3839	708	10.205	4273	4449	8047	6913	124	0	3435	345	3089
March	33968	11490	3602	565	528	7888	77	3803	613	10.536	4152	4395	6443	6910	122	0	3157	499	2658
April	30758	9961	4478	565	931	1413	7	3754	597	10.853	4151	4257	4393	6680	120	0	3663	382	3282
May	32144	8182	4380	565	908	1295	7	3814	289	11.154	4066	4463	6532	5355	129	0	1766	168	1598
June	31286	8038	4787	565	994	1215	6	3783	295	10.656	2807	4414	5351	5546	126	0	1896	227	1669
July	33205	7853	4884	565	1016	1570	8	3808	105	9.312	1451	4458	6145	5788	128	0	1206	2	1203
August	30719	8099	4751	565	989	1634	8	3739	214	7.565	1940	4240	3790	6694	124	0	1933	16	1917
September	31063	6841	4419	565	920	1176	6	3780	198	6.609	3447	4338	5417	6405	133	0	1424	90	1334
October	30671	7696	3514	565	729	648	3	3788	155	6.721	5032	4410	5685	5659	132	0	1220	43	1177
November	32332	9885	3005	565	622	456	2	3829	372	7.617	5286	4461	7710	4910	128	0	2283	274	2009
December	33838	13177	2322	565	478	157	1	3797	432	8.691	5428	4388	6116	6672	119	0	3245	150	3095

Table 32 - Spain 2030 Baseline Scenario – Island Mode

Spanish 2030 Baseline Scenario				Grid stab		50%	i	6%	RES	53.5%	Tot	298.26 TWh		Island mode					
	Electr. Demand	Wind Electr.	PV Electr.	Biomass Electr.	CSP2 Electr.	CSP2 Storage	CSP2 loss	Hydro Electr.	Hydro pump	Storage TWh	Hydro Wat-Sup	Coal Electr.	NG Electr.	Nuclear Electr.	Stabil. Load	Import Electr.	Export Electr.	CEEP Electr.	EEEP Electr.
Annual Average [MW]	32493	9612	3782	565	711	3675	23	4604	1365	9.103	3901	4364	5282	6204	126	0	1266	1266	0
Annual Maximum [MW]	46595	26776	15323	565	2300	17164	7256	5273	6000	11.576	5449	4500	30891	6951	200	0	31789	31789	0
Annual Minimum [MW]	20420	0	0	565	0	0	0	3438	0	6.336	1435	0	0	0	100	0	0	0	0
Sum [TWh/year] - 365d	284.75	84.34	33.16	4.95	6.24	-	0.20	40.33	11.99	-	34.15	38.22	46.28	54.33	-	0.00	11.12	11.12	0.00
Monthly Average Values [MW]																			
January	34712	11470	2592	565	177	12839	70	4701	1276	9.487	4811	4387	6364	6924	126	0	1193	1193	0
February	35254	12729	2621	565	234	14149	76	4769	1868	10.246	4273	4433	7133	6913	124	0	2275	2275	0
March	33968	11490	3602	565	528	7888	77	4632	1669	10.463	4152	4366	5644	6910	122	0	2100	2100	0
April	30758	9961	4478	565	931	1413	7	4442	2095	10.938	4151	4215	3747	6680	120	0	2166	2166	0
May	32144	8182	4380	565	908	1295	7	4672	1066	11.443	4066	4452	5685	5355	129	0	989	989	0
June	31286	8038	4787	565	994	1215	6	4555	1181	10.751	2807	4391	4602	5546	126	0	1010	1010	0
July	33205	7853	4884	565	1016	1570	8	4651	882	9.360	1451	4443	5317	5788	128	0	429	429	0
August	30719	8099	4751	565	989	1634	8	4384	1311	7.610	1940	4187	3197	6694	124	0	837	837	0
September	31063	6841	4419	565	920	1176	6	4545	920	6.692	3447	4305	4685	6405	133	0	702	702	0
October	30671	7696	3514	565	729	648	3	4572	810	6.521	5032	4382	4928	5659	132	0	565	565	0
November	32332	9885	3005	565	622	456	2	4732	1305	7.322	5286	4441	6828	4910	128	0	1351	1351	0
December	33838	13177	2322	565	478	157	1	4606	2030	8.457	5428	4361	5333	6672	119	0	1647	1647	0

Table 33 - Spain 2030 Target Scenario – Interconnected

Spanish 2030 Target Scenario				Grid stab		30%	Interest	6%	RES	74.4%	Tot	316.35 TWh		Interconnected							
	Electr. Demand	Wind Electr.	PV Electr.	Biomass Electr.	CSP2 Electr.	CSP2 Storage	CSP2 loss	Hydro Electr.	Hydro pump	Storage TWh	Hydro Wat-Sup	NG Electr.	Nuclear Electr.	Pump Electr.	Turbine Electr.	Pumped Storage	Stabil. Load	Import Electr.	Export Electr.	CEEP Electr.	EEEP Electr.
Annual Average [MW]	32493	12723	7584	1050	2377	7034	63	4259	934	8.883	3901	6163	2683	71	63	826	158	0	3405	305	3099
Annual Maximum [MW]	46595	35443	30730	1050	7300	54476	27029	6511	9500	10.641	5449	32500	3006	2500	2000	5300	333	1168	35716	24116	11600
Annual Minimum [MW]	20420	0	0	1050	0	0	0	0	0	6.967	1435	0	0	0	0	0	100	0	0	0	0
Sum [TWh/year] - 365d	284.75	111.64	66.51	9.20	20.84		0.55	37.30	8.20	-	34.15	53.93	23.49	0.62	0.55		-	0.00	29.90	2.68	27.22
Monthly Average Values [MW]																					
January	34712	15183	5199	1050	563	40750	223	4887	679	9.223	4811	8302	2994	64	57	199	161	0	2780	350	2431
February	35254	16850	5255	1050	1606	8527	56	4632	949	9.392	4273	7421	2989	59	53	571	154	0	3594	354	3240
March	33968	15210	7224	1050	2310	3333	203	4339	1100	9.345	4152	6068	2988	100	83	703	150	0	4103	639	3464
April	30758	13185	8980	1050	2920	4808	136	3891	1624	9.909	4151	4383	2889	144	129	1925	145	0	4901	614	4287
May	32144	10831	8784	1050	2881	4112	21	4257	835	10.519	4066	5936	2316	60	59	964	161	0	3074	217	2858
June	31286	10639	9600	1050	3154	4016	20	3928	914	10.105	2807	5175	2398	65	53	255	155	0	3732	327	3405
July	33205	10394	9794	1050	3224	4984	25	4137	728	9.006	1451	5805	2503	44	44	583	160	0	2974	58	2916
August	30719	10720	9528	1050	3139	5188	26	3746	1199	7.687	1940	4551	2895	77	69	833	153	0	3704	188	3516
September	31063	9055	8862	1050	2919	3957	20	4047	845	7.158	3447	6297	2770	56	50	2108	174	0	3086	210	2875
October	30671	10187	7047	1050	2313	2058	10	4261	648	7.253	5032	6457	2447	46	41	543	171	0	2440	136	2304
November	32332	13085	6026	1050	1975	1683	8	4554	983	8.142	5286	7376	2123	101	90	1000	164	0	2863	455	2408
December	33838	17443	4657	1050	1517	651	3	4436	722	8.881	5428	6221	2885	32	29	280	146	2	3648	132	3516

Table 34 - Spain 2030 Target Scenario – Island Mode

Spanish 2030 Target Scenario				Grid stab		30%	Interest	6%	RES	74.4%	Tot	303.06 TWh		Island Mode							
	Electr. Demand	Wind Electr.	PV Electr.	Biomass Electr.	CSP2 Electr.	CSP2 Storage	CSP2 loss	Hydro Electr.	Hydro pump	Storage TWh	Hydro Wat-Sup	NG Electr.	Nuclear Electr.	Pump Electr.	Turbine Electr.	Pumped Storage	Stabil. Load	Import Electr.	Export Electr.	CEEP Electr.	EEEP Electr.
Annual Average [MW]	32493	12723	7584	1050	2377	7034	63	5701	2734	8.837	3901	4650	2683	151	135	3912	158	0	1525	1525	0
Annual Maximum [MW]	46595	35443	30730	1050	7300	54476	27029	10685	9500	10.640	5449	29494	3006	2500	2000	5300	333	0	35716	35716	0
Annual Minimum [MW]	20420	0	0	1050	0	0	0	0	0	7.460	1435	0	0	0	0	0	100	0	0	0	0
Sum [TWh/year] - 365d	284.75	111.64	66.51	9.20	20.84		0.55	49.92	24.01	-	34.15	40.69	23.49	1.32	1.18		-	0.00	13.39	13.39	0.00
Monthly Average Values [MW]																					
January	34712	15183	5199	1050	563	40750	223	6816	2164	8.841	4811	6262	2994	188	168	1232	161	0	1172	1172	0
February	35254	16850	5255	1050	1606	8527	56	6312	2845	8.953	4273	5570	2989	252	225	3047	154	0	1505	1505	0
March	33968	15210	7224	1050	2310	3333	203	5751	3034	8.695	4152	4553	2988	215	186	3602	150	0	2054	2054	0
April	30758	13185	8980	1050	2920	4808	136	4956	3732	9.499	4151	3256	2889	215	192	4380	145	0	2723	2723	0
May	32144	10831	8784	1050	2881	4112	21	5666	2529	10.453	4066	4462	2316	134	124	3737	161	0	1307	1307	0
June	31286	10639	9600	1050	3154	4016	20	5162	3011	10.178	2807	3890	2398	121	104	4726	155	0	1580	1580	0
July	33205	10394	9794	1050	3224	4984	25	5518	2582	9.277	1451	4382	2503	95	86	4813	160	0	1069	1069	0
August	30719	10720	9528	1050	3139	5188	26	4840	3060	8.152	1940	3446	2895	90	80	5012	153	0	1829	1829	0
September	31063	9055	8862	1050	2919	3957	20	5528	2550	7.751	3447	4809	2770	64	58	5147	174	0	1373	1373	0
October	30671	10187	7047	1050	2313	2058	10	5772	2053	7.568	5032	4916	2447	80	72	4384	171	0	1001	1001	0
November	32332	13085	6026	1050	1975	1683	8	6227	2123	8.061	5286	5643	2123	161	150	3557	164	0	1663	1663	0
December	33838	17443	4657	1050	1517	651	3	5872	3143	8.632	5428	4639	2885	198	177	3325	146	0	1060	1060	0

Table 35 - Iberia 2030 Target Scenario - Interconnected

Iberia 2030 Target Scenario				Grid stab		30%	Interest	6%	RES	79.4%	Tot	372.36 TWh		Interconnected							
	Electr.	Wind	PV	Biomass	CSP2	CSP2	CSP2	Hydro	Hydro	Storage	Hydro	NG	Nuclear	Pump	Turbine	Pumped	Stabil.	Import	Export	CEEP	EEEP
	Demand	Electr.	Electr.	Electr.	Electr.	Storage	loss	Electr.	pump	TWh	Wat-Sup	Electr.	Electr.	Electr.	Electr.	Storage	Load	Electr.	Electr.	Electr.	Electr.
Annual Average [MW]	38626	15050	9495	1400	2393	11187	83	7175	2235	10.889	5984	6076	2683	110	99	1629	158	0	3400	765	2634
Annual Maximum [MW]	56460	41926	38475	1400	7600	56715	27247	12313	13080	14.950	9355	35101	3006	2500	2500	5300	333	0	42620	34620	8000
Annual Minimum [MW]	24881	0	0	1400	0	0	0	0	0	6.058	1356	0	0	0	0	0	100	0	0	0	0
Sum [TWh/year] - 365d	338.49	132.06	83.27	12.26	20.98		0.73	62.84	19.63	-	52.33	53.17	23.49	0.97	0.87		-	0.00	29.86	6.72	23.13
Monthly Average Values [MW]																					
January	41415	17960	6509	1400	617	42552	232	8126	1585	11.334	9087	8159	2994	81	73	264	161	0	2757	713	2044
February	42250	19932	6580	1400	775	47091	252	8045	2143	12.814	8547	8006	2989	116	104	533	155	0	3322	693	2628
March	40367	17992	9045	1400	2240	13870	267	7283	2526	13.167	6292	6079	2988	135	114	881	150	0	4114	1248	2866
April	36331	15597	11244	1400	3047	4784	119	6470	3396	14.044	6191	4177	2889	193	172	3000	144	0	5075	1578	3497
May	38246	12811	10997	1400	3000	4281	22	7111	2060	14.703	5292	5777	2316	99	95	966	160	0	3101	604	2497
June	37145	12585	12020	1400	3284	4093	21	6637	2473	13.628	3605	5001	2398	105	87	1171	155	0	3690	759	2930
July	39308	12296	12263	1400	3357	5189	26	6977	2114	11.508	1359	5618	2503	84	81	1202	159	0	2988	336	2652
August	36394	12681	11930	1400	3268	5401	27	6359	2831	8.703	1525	4403	2895	125	105	3177	152	0	3691	792	2899
September	36858	10712	11096	1400	3039	4015	20	6969	2144	6.909	3867	6165	2770	86	84	2414	173	0	3147	637	2510
October	36547	12051	8824	1400	2408	2142	11	7204	1614	6.383	7672	6320	2447	79	69	2361	171	0	2483	459	2023
November	38550	15478	7545	1400	2056	1582	8	7630	1795	7.889	9140	7237	2123	127	115	2520	164	0	3112	1026	2086
December	40153	20633	5830	1400	1580	585	3	7315	2157	9.680	9355	6038	2885	97	86	1071	146	0	3361	365	2997

Table 36 - Iberia 2030 Target Scenario – Island Mode

Iberia 2030 Target Scenario				Grid stab		30%	Interest	6%	RES	81.9%	Tot	361.16 TWh		Island Mode							
	Electr.	Wind	PV	Biomass	CSP2	CSP2	CSP2	Hydro	Hydro	Storage	Hydro	NG	Nuclear	Pump	Turbine	Pumped	Stabil.	Import	Export	CEEP	EEEP
	Demand	Electr.	Electr.	Electr.	Electr.	Storage	loss	Electr.	pump	TWh	Wat-Sup	Electr.	Electr.	Electr.	Electr.	Storage	Load	Electr.	Electr.	Electr.	Electr.
Annual Average [MW]	38626	15050	9495	1400	2393	11187	83	8411	3778	10.757	5984	4800	2683	155	139	3646	158	0	1812	1812	0
Annual Maximum [MW]	56460	41926	38475	1400	7600	56715	27247	16456	13080	14.811	9355	30957	3006	2500	2500	5300	333	0	42620	42620	0
Annual Minimum [MW]	24881	0	0	1400	0	0	0	0	0	6.353	1356	0	0	0	0	0	100	0	0	0	0
Sum [TWh/year] - 365d	338.49	132.06	83.27	12.26	20.98		0.73	73.66	33.18	-	52.33	42.00	23.49	1.36	1.22		-	0.00	15.92	15.92	0.00
Monthly Average Values [MW]																					
January	41415	17960	6509	1400	617	42552	232	9773	2881	11.028	9087	6425	2994	179	160	1261	161	0	1362	1362	0
February	42250	19932	6580	1400	775	47091	252	9638	3757	12.418	8547	6309	2989	233	208	1290	155	0	1591	1591	0
March	40367	17992	9045	1400	2240	13870	267	8520	4158	12.472	6292	4772	2988	213	184	3222	150	0	2404	2404	0
April	36331	15597	11244	1400	3047	4784	119	7349	5129	13.531	6191	3277	2889	217	193	4390	144	0	3319	3319	0
May	38246	12811	10997	1400	3000	4281	22	8297	3561	14.484	5292	4551	2316	143	134	3369	160	0	1556	1556	0
June	37145	12585	12020	1400	3284	4093	21	7666	4217	13.537	3605	3945	2398	136	115	4651	155	0	1915	1915	0
July	39308	12296	12263	1400	3357	5189	26	8130	3744	11.611	1359	4432	2503	128	114	4683	159	0	1313	1313	0
August	36394	12681	11930	1400	3268	5401	27	7270	4284	9.004	1525	3496	2895	112	100	4888	152	0	2250	2250	0
September	36858	10712	11096	1400	3039	4015	20	8230	3618	7.270	3867	4913	2770	85	76	5109	173	0	1675	1675	0
October	36547	12051	8824	1400	2408	2142	11	8491	2877	6.547	7672	5021	2447	90	81	4255	171	0	1209	1209	0
November	38550	15478	7545	1400	2056	1582	8	9074	2918	7.777	9140	5769	2123	148	139	3440	164	0	1968	1968	0
December	40153	20633	5830	1400	1580	585	3	8532	4211	9.477	9355	4744	2885	184	164	3141	146	0	1220	1220	0