NATIONAL ENERGY AND CLIMATE PLAN 2030: MODELLING THE IBERIAN POWER SYSTEM UNDER THE NEW EUROPEAN POLICY FRAMEWORK

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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.

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 (EC) proposal published on 30th November 2016. The aim of the proposal consisted of the completion of the "Clean energy for all Europeans package" (CEP), a new energy rulebook 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 [1], Member States (MS) are required to disclose and communicate their long-term strategies and national targets to the EC by developing Integrated National Energy and Climate Plans (NECPs) for the period 2021-2030. This report has to be based on a common template provided by the EC, covering the five dimensions of the Energy Union: energy security, solidarity and trust; a fully integrated internal energy market; energy efficiency; climate action - decarbonisation of the economy; research, innovation and competitiveness.

1.1 Scope of the work

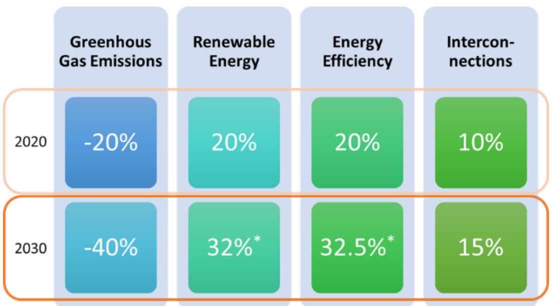
The EC itself always promotes bilateral collaboration among MS to enhance regional cooperation, facilitating market integration and cost-efficient policies and measures. However, each NECP is a national plan and its assumptions might be limited to the national boundaries, as highlighted by the European Commission Energy Policy Coordination working group, which assessed the NECPs [2]. In specific, looking at the renewable energy and interconnection targets within Iberian market, the ability of the future electric system to manage the high penetration of renewables must be investigated in order to confirm the coping of the Portuguese and Spanish NECPs, considered among the most ambitious of the EU28 [3]. Inconsistencies between neighbouring countries' long-term plans may incur in deviations, leading to the overshooting of the national and European targets [4].

Hence, taking into considerations the Iberian 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 (PT) and Spain (ESP), 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 NECP, focusing especially on the effect of the increasing penetration of renewables.

2 Clean Energy Package

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%, consisting of a reduction in primary energy consumption compared to the Baseline scenario, namely projections made in years 2007 for primary energy consumption [5]. Figure 1 shows the EU targets regarding Renewables Sources (RES), Energy Efficiency (EE), GHGs and interconnection level, whilst Table 1 presents a compilation of the main topics in each of the eight dossiers that constitutes the CEP.



* To be reviewed in 2023 (only upwards)

Figure 1 - EU targets of RES, EE & GHGs for 2020 and 2030 [5]

Table 1 - Directives of the CEP [5]

#	PACKAGE	CONTENT
1	Energy Performance in Buildings	- Path towards zero-emissions buildings by 2050 - Smart readiness indicator - Building renovation
2	Renewable Energy	- Renewable Energy, emissions and Interconnection targets
3	Energy Efficiency	- Energy efficiency target - Energy savings in households, transport and industry
4	Governance of the Energy Union	- Governance mechanisms - NECPs
5-6	Electricity Regulation & Directive	- Common rules for the internal electricity market
7	Risk Preparedness	- Tools to prevent, prepare for and manage electricity crisis
8	ACER	- Establishing a European Union Agency for the Cooperation of Energy Regulators

3 Overview: Iberian power system

The energy balance flow diagram in Figure 2 displays the current state of the Iberian energy system, which is a net importer (163 Mtoe imports over 41 Mtoe exports) and hence characterized by a high energy dependency (E_{dep}). Transformation losses (34 Mtoe) represents 20.7% of the transformation inputs, losses occurring prevalently within the electricity sector, with a transformation efficiency of 46.6%. Fossil fuels still dominate the final energy consumption (48%), while electricity accounts for 25.5%, higher than the EU average (around 20%) [6]

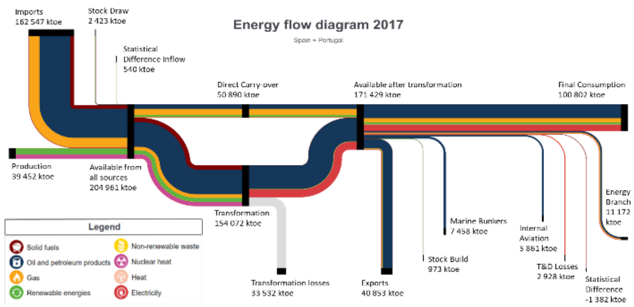


Figure 2 – Iberian Peninsula Energy Balance in 2017 [7]

In 2017, the Iberia peninsula emitted 411 Mton of CO_2 equivalent (international aviation, Land use, land-use change, and forestry excluded), with 102 Mton coming from energy sector (heat and electricity), which represents 25% of the total GHGs emissions [6].

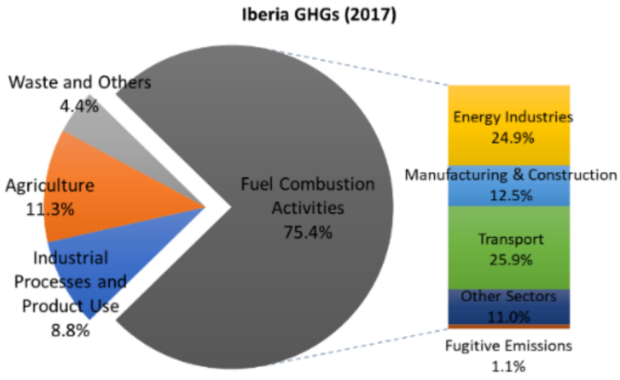


Figure 3 - Iberian Peninsula 2017 GHGs Emissions (LULUCF excl.) [6]

3.1 Generation

In 2017, the total installed generation capacity was equivalent to 20.9 GW in Portugal and to 103.8 GW in Spain: 59.43 TWh and 275.64 TWh were generated, as shown in Figure 4, achieving a RES share 40.6% and 32.9% respectively.

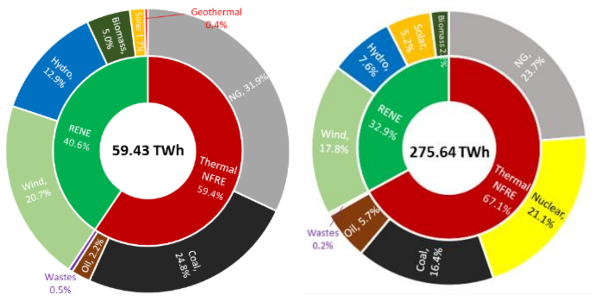


Figure 4 - Electricity production: Portugal and Spain (2017)

However, 2017 was not a highly favourable hydrological year, which meant lower availability of hydro resources to produce electricity [8], whose production was halved compared to 2016.

3.2 Interconnections

Located in a peripheral region of the European Union, the two Iberian countries are still below the interconnection (INT) target of 10% established by the European Commission by 2020, respectively with 6% and 9% for Spain and Portugal [9].

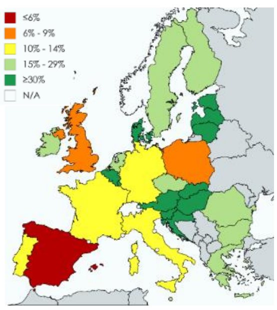


Figure 5 - Expected EU28 interconnection levels in 2020 [9]

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 7%, as shown in Figure 5.

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 3016 MW (Portugal->Spain) and 2000 MW (Spain->Portugal), with regards to the expected evolution of interconnection capacity, the minimum indicative values for PT/ESP are presented in Figure 6.

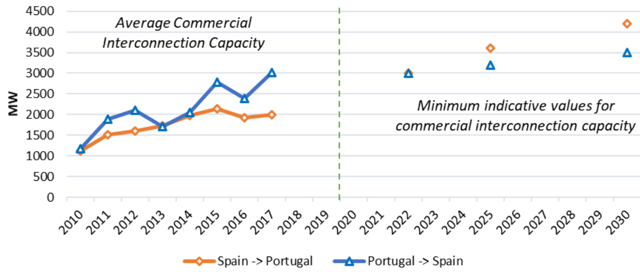


Figure 6 - Interconnection capacity evolution: PT – ESP

Additional investment projects to reinforce the interconnections with other non-Iberian countries are planned as well: for Portugal, the Morocco interconnection project (1000 MW) is currently being studied and expected to be completed by 2030; for Spain three new interconnection projects with France are planned, increasing interconnection capacity up to 8000 MW.

3.3 Electricity demand and loads

The evolution of the electricity demand of the Iberian Peninsula is presented in Table 2, with both countries experiencing a 4.2% growth over the last 4 years (2014-2018).

Table 2 - Iberia: evolution of electricity demand [10] [11]

	PORTUGAL		SPAIN	
Year	**Demand**	**Delta**	**Demand**	**Delta**
2014	48.8	-0.7%	243.2	-1.1%
2015	49	0.3%	248	2.0%
2016	49.3	0.6%	249.7	0.7%
2017	49.6	0.7%	252.5	1.1%
2018	50.9	2.5%	253.5	0.4%
Unit	*TWh*	-	*TWh*	-

4 National Energy and Climate Plans

Figure 7 depicts the timeline of NECPs elaboration, from the presentation of the CEP in 2016 until the revised NECPs which will be published in 2024.

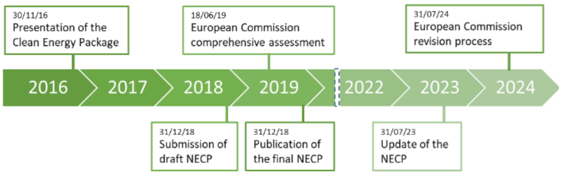


Figure 7 - Timeline of NECPs elaboration

4.1 Main targets

Table 3 and Table 4 shows national targets and contributions for energy and climate defined for the 2030 horizon by the PNEC and INECP respectively.

Table 3 - Portuguese energy and climate targets [12]

	RES	EE	GHGs	E_{dep}	RES_{el}	INT
2017	28%	23%	-22%	80%	54%	8%
2020	31%	25%	-21%	74%	60%	10%
2030	47%	35%	-50%	65%	80%	15%

Portuguese GHGs consists of the average for 2020 (18-23%) and 2030 (45-55%)

Table 4 - Spanish energy and climate targets [13]

	RES	EE	GHGs	E_{dep}	RES_{el}	INT
2017	18%	23%	-21%	74%	36%	6%
2020	20%	26%	-25%	71%	40%	10%
2030	42%	40%	-48%	59%	74%	15%

Both Portugal and Spain aspire to reinforce the weighting of renewable energies aiming at an ambitious 47% and 42% RES target, equivalent to respectively 16% and 22% points of difference between 2020 and 2030. Portugal is expected to remain a more energy dependent country than Spain.

4.2 Generation system

Figure 8 illustrate the evolution's perspectives of the installed capacity divided by technology in Portugal and Spain.

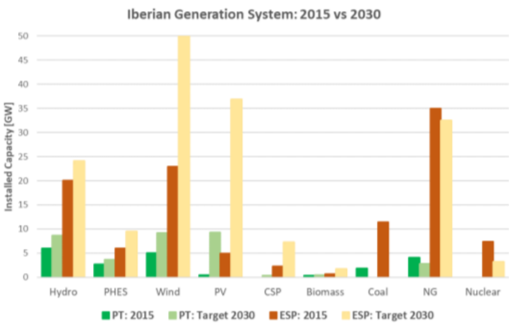


Figure 8 - Iberian generation system [13] [14]

The aforementioned capacity is expected to contribute for an increase of 26% (Portugal) and 38% (Spain) of the RES share in the final electricity consumption, as shown in Figure 9. Iberia will be characterized by a huge deployment of RES technologies in the next decade with +40 GW and +31 GW of new solar and wind capacity (respectively 770% and 112% of relative growth compared to 2015). Thermal power plants (NFER) will start a phase out process starting from coal in both countries, followed by Nuclear in Spain by 2035.

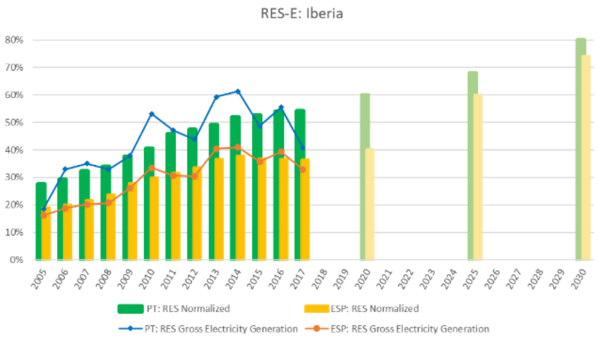


Figure 9 – RES_{el} Evolution & targets: Spain and Portugal [15]

4.3 EC Assessment

As previously shown in Figure 7, on June 2019 the EC has released a comprehensive assessment in which all the NECPs of the different member states are evaluated, whose main outcomes for Portugal and Spain are analysed and summarized in Table 5 (reasoning at the bottom). Even though ambitious targets were submitted by several countries (including Portugal, Spain, Lithuania, Denmark and Estonia), 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% in 2030 at Union level, still below the 32% binding target established by the EC [3].

Table 5 - EC Comprehensive Assessment: summary [3]

TOPIC	ACTION	Portugal	Spain
Renewables	Ambition	☑	☑
"	Trajectories	⌃	⌃
H&C	Ambition	☒	☑
Transport	Ambition	⌃	☑
Self-consumption	Administrative procedures	⌃	⌃
Energy efficiency	Ambition	☒	⌃
Energy security	Measures	☑	⌃
Nuclear	Phase-out	☐	⌃

Market integration electricity/gas	Fully and competitive market-based prices	⍓	⍓
Cooperation	Regional	⍓	⍓
Investments & Funding	Overview	☒	☑
"	R&D Targets	⍓	⍓
Energy subsidies	Listing	☒	☒
Air quality	Policy analysis	⍓	☑
Energy transition	Just and fair	⍓	☑
"	Energy poverty	⍓	☑
Publication	Deadline	☑	☒
Reasoning	☑: adequate ambition/no comments ☒: info missing or substantially increase ambition	⍓: provide more info/put forward measures ☐: not mentioned/relevant for the country	

4.4 NECP 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. The PNEC does not provided further detailed information regarding the modelling input and output, except from the table with technologies costs considered in the TIMES_PT model, which have been used as support to this case study, as reported in Table 8. On the other hand, the INEC presents the results of the generation dispatch, export and imports for the 2030 Baseline and Target Scenarios, as shown in Figure 10.

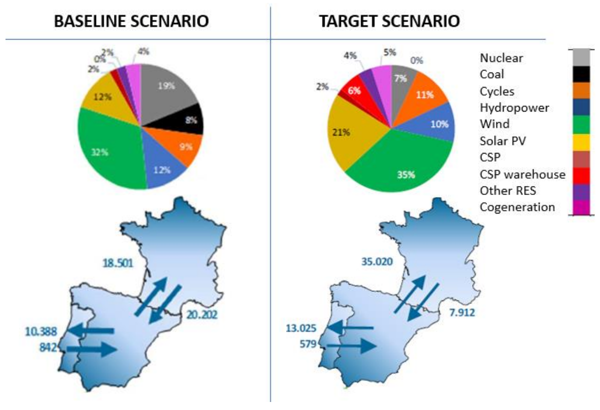


Figure 10 – Spain 2030 Scenarios: exchanges balance [13]

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 model outputs, 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.

5 Methodology

The 2030 Scenarios will be modelled with the utilisation of EnergyPLAN, a deterministic input/output computer model which optimises the operation of a given energy system in a specific year, on hourly time-steps. Through the analysis of the NECPs, ENTSO-E and EC reports, the data required to run the simulation was collected. Then, the model was successfully validated for Portugal, comparing the results for 2017 with yearly statistics provided by REN (Portuguese TSO) [10]. The simulation consisted of a technical analysis of Portugal and Spain, firstly separated and then aggregated in the Iberia setting, concluding with a sensitivity analysis and comments on the results obtained. Figure 11 shows the main steps of the methodology, whilst Figure 12 provides a detailed overview of the inputs and the outputs of the model. 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

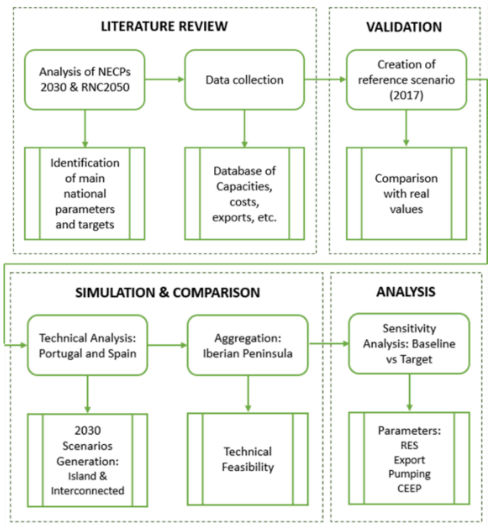


Figure 11 – Methodology

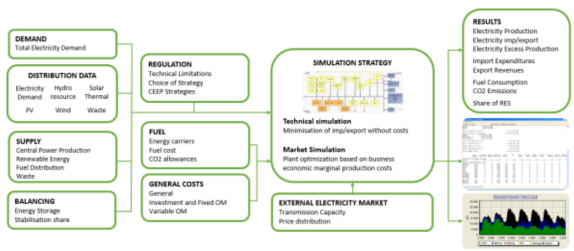


Figure 12 - EnergyPLAN: inputs & outputs [16]

5.1 Demand

Regarding the future shape of the hourly demand profile, ENTSO-E has recently published its Ten Year Network Development Plan (TYNDP) 2018 Report, where the "Sustainable Transition (ST)" Scenario is defined, together with the yearly total electricity demand for 2030 [17].

Table 6 - TYNDP Load forecast for 2030 [17]

	PT	ESP	IBERIA	*UNIT*
El_{demand}	53.74	284.75	338.49	*TWh*
Peak Load	10.01	46.6	56.46	*GW*
Min Load	3.56	20.42	24.88	*GW*

5.2 Grid balancing

Synchronous generators have the fundamental role of stabilising and maintaining the grid 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 [18].

5.3 Supply

There are two types of supply: centralized power plants production and variable renewable production. In the model, the electricity production is aggregate, which means that a unique value of installed capacity C_{tech} is required for each technology. Thermal power plants included in the modelling are coal, natural gas (NG), nuclear and dammed hydro, whose overall efficiencies were set to respectively 38%, 45%, 33% and 90% [17]. To complete its operational parameters, hydropower requires storage capacity of reservoirs [1] [GWh], pump back efficiency η_{PHES} and total water supply W_{supply_2030} [TWh/year] (distributed throughout the year according to the average monthly precipitations), calculated for 2030 using the average capacity factor CF_{avg} over the last 10 years (2009-2018) [10] and the planned installed capacity C_{hydro_2030}:

$$W_{supply} = \frac{C_{hydro} * CF_{avg\_10yr} * 8760\ hrs}{\eta_{hydro}} \qquad (1)$$

[1] Assumed to be 50% full at the beginning of the year

As far as renewable energy sources are concerned, the additional information required to determine the hourly electricity generation are:

- $\delta_{RES,k}$: normalized hourly distribution profile (8784 values between 0 and 1), obtained utilizing the year 2017 distribution by dividing the real hourly generation by the total installed capacity;
- $f_{stab,RES}$: share of the electricity produced by RES contributing to grid stability[2] (between 0 and 1);
- $f_{C,RES}$: correction factor, which adjusts the hourly distribution inputted for the renewable resource to model future improvements of the technology, as shown in the equation below.

$$El_{RES} = \sum_{k}^{N=8784} C_{RES} * \delta_{RES,k} * \frac{1}{[1 - f_{C,RES} * (1 - \delta_{RES,k})]} \qquad (2)$$

Concentrated Solar Power (CSP) has been modelled by consulting SolarPACES data provided by the National Renewable Energy Laboratory (NREL), where it can be found that installed Spanish CSP have a maximum capacity of 50 MW each, an average yearly field electricity generation El_{CSP_avg} of 150 GWh/year and 7.5 hours of storage capacity (equivalent to 375 MWh) [19]. Hence, the annual solar input S_{input} to CSP plants in 2030 was obtained as follows:

$$S_{input} = \frac{C_{CSP}/_{50\ MW} * El_{CSP\_year\_avg}}{\eta_{CSP}} \qquad (3)$$

5.4 Import/Export

The interconnection line capacity [MW] can be specified (constant and equal in both exchange directions), which connects the modelled energy system to an external one. Apart from the maximum capacity, there are no other constraints on export, which is always the first option in case of Excess Electricity Production (EPP). When this capacity is fully exploited, then pumped hydro starts to store energy (if the reservoir is not full), in combination with battery storage (if available). When the technologies mentioned above are fully exploited or not available, then Critical Excess Electricity Production (CEEP) occurs: in this case, electricity is curtalide. Import occurs only if the generation system cannot satisfy the demand by itself.

[2] Biomass and CSP are assumed to provide grid stability

5.5 Fuel

The forecasted fuel market price, emission allowances and emission factors are included in Table 7.

Table 7 – Fuel and emission allowances market price (plus emission factors per technology) [20] [17]

	UNIT	2015	2030	f_{CO_2}
Oil (crude)	$€/GJ$	7.63	14.52	74
Natural Gas	$€/GJ$	6.6	8.79	57
Coal	$€/GJ$	1.91	3.18	94
Nuclear	$€/GJ$	0.47	0.47	-
Emission all.	$\frac{€}{ton_{CO_2}}$	5.8	20 - 34	$\frac{kg_{CO_2}}{net\ GJ}$

CO_2 price included represents respectively the Baseline & Target Scenarios

5.6 Costs

Table 8 contains the main technologies costs obtained from the TIMES_PT model, together with their lifetime.

Table 8 - Cost of the main technologies [12] [18]

	2016		2030		GENERAL	
	P_{unit}	O&M$_f$	Inv	O&M$_f$	Life	O&M$_v$
Unit	€/W	%	€/W	%	Yrs	€/MWh
Coal	1.9	1.84	2.3	1.52	30	3.4
NG	0.8	2.75	0.765	2.75	30	2.76
Biomass	4.7	1.00	4.23	0.95	-	0.71
Waste	2.03	2.56	2.01	2.19	-	0.81
PV	0.7	1.86	0.645	1.89	25	-
CSP	5.1	2.00	4.59	2.00	30	-
Wind	1	1.80	0.98	1.84	25	-
Hydro	1.4	2.86	1.4	2.86	50	-
PHES	2.8	2.14	2.8	2.14	50	-
Battery	2.1	2.14	1	4.50	15	-

With those information, the total investment cost I_{tech} [M€], the annual investment cost A_{tech} [M€/year] and annual fixed O&M cost $A_{O\&M\_tech}$ [M€/year] are computed for each technology:

$$I_{tech} = P_{unit} * C_{tech} \qquad (4)$$

$$A_{tech} = I_{tech} * \frac{i}{1-(1+i)^{-n}} \qquad (5)$$

$$A_{O\&M\_tech} = I_{tech} * O\&M_{fix}[\%] \qquad (6)$$

5.7 Simulation

The main objective of the technical simulation is to balance supply and demand of the energy system minimising fossil fuel consumption. It is 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. The primary variables chosen to be recorded by the model when comparing alternative energy systems are:

- RES [%] : Share of renewable energy in the final energy consumption [TWh/year];

$$RES\ [\%] = \frac{El_{PV+wind} + El_{bio} + (El_{hyd} - El_{PH} * \eta_{PH})}{El_{tot\_production}} \qquad (7)$$

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

6 Future Scenarios - 2030: results

Chapter 6 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 Target Scenario for Portugal will be generated, due to the fact that no Baseline Scenario is specified in the PNEC, but only specifies two ranges for wind and solar, which have been named "Low-RES & High-RES Scenario". A sensitivity analysis between the 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 as well. Then, the two countries are aggregated to model the Iberian Peninsula, with the cumulative capacity installed, distribution profiles, hydropower input and demand curve; only the interconnection between Spain and France will be considered (not between Iberia and Morocco).

All the Scenarios are analysed in two different modalities: interconnected and island mode, in order to analyse how a certain energy system manages the EPP according to the boundary conditions. In particular, regardless the Scenario or simulation performed, the excess electricity production (EEP) measured within a system is always equivalent to the sum between electricity exported (El_{export}), electricity consumed by pumping (El_{pump}) or stored through batteries (El_{bat}) and critical excess electricity production ($CEEP$), as shown in the equation below and verified in all the simulations:

$$EEP = El_{export} + El_{pump} + El_{bat} + CEEP \qquad (8)$$

6.1 Portugal

6.1.1 Target Scenario

The Low-RES Target Scenario for Portugal is presented below in Table 9 and Figure 13.

Table 9 – PT Low-RES 2030 Target Scenario: main outcomes

	INTERCONNECTED				ISLAND MODE		
	C_i	El_p	Shar	CF	El_p	Shar	CF
Unit	*GW*	*TWh*	*%*	*%*	*TWh*	*%*	*%*
Hydr	8.7	16.2	25.8	21.2	16.0	28.1	21.0
Wind	8.8	22.0	35.0	28.5	22.0	38.5	28.5
Biom	0.5	3.7	5.9	84	3.7	6.4	84.0
PV	7.8	14.1	22.4	20.6	14.1	24.6	20.6
CSP	0.3	0.8	1.3	30.3	0.80	1.4	30.3
NG	2.8	6.0	9.6	24.5	0.5	0.9	2.2
PHES	3.6	-1.7	-	5.6	-8.9	-	28.3
Exp	3.6	-8.9	-	28.2	0	-	0
CEEP	-	**-0.2**	-	-	**-1.97**	-	-

Cogeneration not included for the Portuguese case

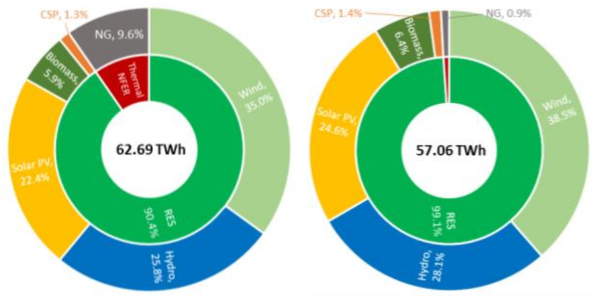


Figure 13 - PT Low-RES 2030 Target Scenario: El_{prod}

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. The absence of cogeneration (which for Portugal is currently based on 75% natural gas and 25% biomass [12]) is the main cause of the renewable share overestimation in the final electricity consumption. If cogeneration is included in the modelling, assumed to not contribute to grid stability and without substantial modifications in the cogeneration energy mix by 2030, it will cause the RES share to decrease.

The electricity excess reported includes 30% of electricity from synchronous generators (NG, hydro, biomass, CSP or nuclear), meaning that for each 1 MWh produced, 0.3 MWh must come from grid stabilising units. If dispatched (exported or pumped), then the EPP does not vary; if directly curtailed, then the effective EPP is only 70%. Hence, under the Low-RES Scenario, the EPP adjusted EEP_{adj} will represents 21.1% of the total variable RES production, increasing to 26.6% in the High-RES Scenario, meaning that Portugal will greatly overproduce electricity:

$$EEP_{adj}[\%] = \frac{EPP * (1 - f_{grid})}{El_{PV} + El_{wind}} \quad (9)$$

The same computation methodology can be applied to the CEEP. Furthermore, with such high penetration of variable RES, it becomes challenging for the grid to stay above the minimum grid stabilisation share f_{grid} of 30%.

6.2 Spain

The INECP provides all the necessary information to model both 2030 Baseline and Target Scenario, however only the latter has been analysed in depth.

6.2.1 Baseline Scenario

For the Baseline, almost identical results were obtained for interconnected (305.4 TWh), island (298.3 TWh) and INECP (295.5 TWh) achieving 52.2%, 53.5% and 54.8% of RES respectively.

6.2.2 Target Scenario

As it can be seen from Table 10 and Figure 14, the modelling outcomes of the Spain 2030 Target Scenario interconnected and island mode are coherent with the results presented by the INECP (in order 316.35 TWh, 303.06 TWh and 329.1 TWh of El_{prod}; 75.5%, 78.8% and 74.4% of RES). Deviations occurs since some technologies were not modelled (e.g. renewables cogeneration, marine, geothermal, waste, etc.), export is greater and import was modelled in the INECP only.

Table 10 - ESP 2030 Target Scenario: main parameters

		INTERCONNECTED			ISLAND MODE		
	C_i	El_p	Shar	CF	El_p	Shar	CF
Unit	GW	*TWh*	*%*	*%*	*TWh*	*%*	*%*
Hydr	24.1	30.7	9.7	14.6	30.7	10.1	14.5
Wind	50.3	111.6	35.3	25.3	1116	36.8	25.3
Biom	1.7	9.2	2.9	62.6	9.2	3.0	62.6
PV	36.9	66.5	21.0	20.6	66.5	21.9	20.6
CSP	7.3	20.8	6.6	32.6	20.8	6.9	32.6
NG	32.5	53.9	17.0	18.9	40.7	13.4	14.3
Nucl	3.2	23.5	7.4	83.8	23.5	7.8	83.8
PHES	9.5	-8.2	-	9.9	-24.0	-	28.8

Bat	2.5	-0.62	-	2.8	-1.32	-	6.0
Exp	11.6	-27.2	-	26.8	0	-	0.0
CEEP	-	**-2.68**	-	-	**-13.4**	-	-

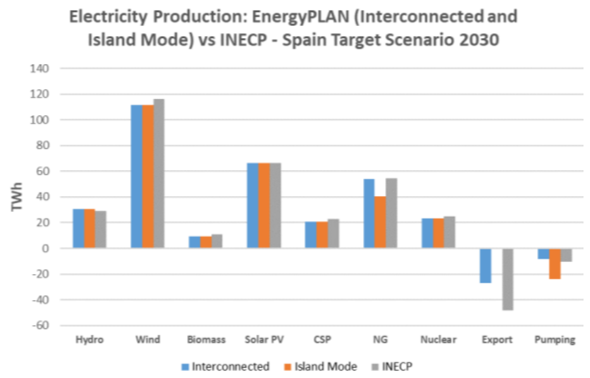


Figure 14 - ESP 2030 Target Scenario El_{prod} comparison: interconnected vs island vs INECP

6.3 Iberia

Spain Target Scenario and Portugal High-RES Scenario are coupled to model the Iberian Peninsula, as described at the beginning of this chapter.

Table 11 - Iberia 2030 High-RES Target Scenario: main parameters

		INTERCONNECTED			ISLAND MODE		
	C_i	El_p	Shar	CF	El_p	Shar	CF
Unit	GW	*TWh*	*%*	*%*	*TWh*	*%*	*%*
Hydr	32.8	47.1	12.7	16.4	47.1	13.0	16.4
Wind	59.5	132.1	35.5	25.3	1321	36.6	25.3
Biom	2.18	12.3	3.3	64.3	12.3	3.4	64.3
PV	46.2	83.3	22.4	20.6	83.3	23.1	20.6
CSP	7.6	21.0	5.6	31.5	21.0	5.8	31.5
NG	35.3	53.2	14.3	17.2	42.0	11.6	13.6
Nucl	3.2	23.5	6.3	83.8	23.5	6.5	83.8
PHES	13.1	-19.6	-	17.1	-33.2	-	29.0
Bat	2.5	-0.97	-	4.4	-1.36	-	6.2
Exp	8	-23.1	-	33.0	0.0	-	0.0
CEEP	-	**-6.72**	-	-	**-15.9**	-	-

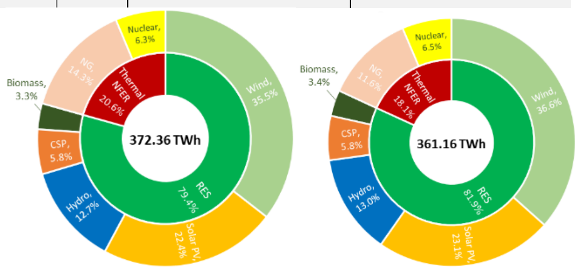


Figure 15 - Iberia 2030 High-RES Target Scenario: El_{prod}

6.4 Comparison

As demonstrated, 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. This phenomenon can be effectively measure by $CEEP_{adj}$ parameter, which measures ratio between curtailed electricity and electricity production under island operations.

Table 12 - Electricity excess production (2030 High-RES Target Scenario)

	PORTUGAL	SPAIN	IBERIA	*Unit*
$El_{PV,wind}$	39.8	178.1	215.4	*TWh*
EEP_{adj}	26.6%	15.2%	16.4%	-
$CEEP_{adj\_isl}$	10.8%	5.3%	5.2%	-

One of the theoretical benefits of the aggregation between the two Iberian countries can be noticed with the decrease of the CEEP in the Iberia setting compared to Spain and Portugal: a higher interconnection capacity (assumed infinite if two countries are aggregated) favours the integration of renewable energy in neighbouring Member States, especially the ones located in the peripheral part of the EU.

The interconnected case study is characterized by an extremely optimistic electricity export, occurring prevalently during daytime, whilst in island mode PHES achieves a capacity factor close to 30% (almost three times current PHES CF). In this case, hydro substitutes NG for managing the grid stability, often operating together with the pumps, explaining the higher RES share achieved in island mode.

7 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.

The electricity excess phenomenon is expected to become significant in the Iberian Peninsula: with an expected interconnection level of 4.3%, the high penetration for renewables will be tackled prevalently through pumping, storing or curtailment rather than export. 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 optimal EPP distribution.

Wind will become the predominant source of electricity in the Iberian Peninsula, expecting around 35% of the final electricity produced in Iberia by 2030 and followed by solar PV with 24%. However, in a system with high penetration of renewables, additional installation of RES will not lead to a proportional growth of the RES share. Developing a compatible policy framework for energy systems with high penetration of renewables, investments in storage facilities and the cooperation between Member States will be of crucial importance to advance towards 100% renewable electricity systems.

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 still lacks several information such as flow of investments and the expected electricity generation by 2030. Finally, the consultation of other Member States' National Energy and Climate Plans is strongly advised to improve the quality and the consistency of the NECP.

8 Bibliography

[1] European Commission - CEP: Governance, "Governance of the Energy Union and Climate Action Rules," 2018.

[2] P. Pinho, Interviewee, *Shaping EU's Energy Future: making NECPs come to life.* [Interview]. 18 June 2019.

[3] European Commission - NECPs Recommendation, "Commission Recommendation on the draft integrated National Energy and Climate Plan covering the period 2021-2030," Brussels, 2019.

[4] A. Pina, Interviewee, *Personal communication on PNEC.* [Interview]. 28 June 2019.

[5] European Commission - CEP, 2019. [Online]. Available: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans.

[6] European Commission - Energy Datasheet, "EU energy in figures: statistical pocketbook," 17 07 2019. [Online]. Available: https://ec.europa.eu/energy/en/data-analysis/energy-statistical-pocketbook.

[7] Eurostat - Energy Balance, "Energy balance flow for European Union (28 countries)," 03 September 2019. [Online]. Available: https://ec.europa.eu/eurostat/cache/sankey/sankey.html.

[8] A. Mendes, "Produção das barragens da EDP afundou 55% em 2017 devido à seca," 24 January 2018. [Online]. Available: https://www.jornaldenegocios.pt/empresas/energia/detalhe/producao-das-barragens-da-edp-afundou-55-em-2017-devido-a-seca.

[9] ENTSO-E: Winter Outlook, "Winter Outlook 2016/17," 2017.

[10] REN - Estatística Anual, "Electricidade: Estatística Anual 2009-2018," Lisbon, 2019.

[11] RED - Report, "The Spanish Electricity System," 2019.

[12] Draft PNEC, "Plano Nacional Integrado Energia e Clima 2021-2030," 2018.

[13] Draft INECP, "Borrador del Plan Nacional Integrado de Energía y Clima," Madrid, 2019.

[14] PNEC - Consulta Pública, "Plano Nacional Energia e Clima - Consulta Pública," 2019.

[15] Eurostat - Renewables, "Renewable Energy Statistics," 2019. [Online].

[16] D. Connolly, H. Lund and B. Mathiesen, "Smart Energy Systems: Holistic and Integrated Energy Systems for the era of 100% Renewable Energy.," Aalborg University, 2013.

[17] ENTSO-E: TYNDP, "TYNDP 2018 Scenario Report," 2018. [Online]. Available: https://tyndp.entsoe.eu/maps-data/.

[18] H. Lund and J. Z. Thellufsen, "Advanced Energy Systems Analysis Computer Model - Documentation Version 14," Aalborg University, 2018.

[19] NREL, "Concentrating Solar Power Projects," 2019. [Online]. Available: https://solarpaces.nrel.gov/.

[20] European Commission - Reference Scenario, "EU Reference Scenario 2016," 2016.