UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master’s Thesis

IMPACT OF EU 2030 CLIMATE AND ENERGY POLICIES ON THE IBERIAN ELECTRICITY MARKET

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Summary

While the EU is making good progress towards meeting its climate and energy targets for 2020 (EC, 2015a), an integrated policy framework 2020 onwards is needed to ensure regulatory certainty for investors and a coordinated approach among Member States (EU, 2014abcd).

In this context, the former European Commission launched two communications in 2014 ("A policy framework for climate and energy in the period from 2020 to 2030"(EC, 2014a) and "Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy"(EC, 2014b)) which set the basis for the 2030 objectives approved by the European Council by the end of 2014(EC): at least 40% greenhouse gas emissions reduction; at least 27% of renewable energy share; at least 27% increasing of energy efficiency and 15% electricity interconnection target.

Now the debate is moving from strategy to action, from long-term vision to actual policies and regulations, looking for the most appropriate tools and mechanisms to achieve the targets in the most effective, efficient and equitable manner.

This thesis aims to modestly contribute to this debate by:

- Developing a simplified model of one of the relevant electricity markets in Europe, the Iberian electricity market (MIBEL), which could be eventually used as a tool for assessing the effects of potential European energy and climate policies in the electricity sector;
- Running a first hypothetical case study with this model in order to test it, and show some of their potential uses when assessing European energy policies.

The case study aims to assess potential effects in the Iberian electricity market of different scenarios of CO_2 prices and renewable energy market shares (up to 2030), which are variables that will be affected by the European energy policy that will be developed and implemented in the next years in order to achieve the European 2030 targets. Notwithstanding, the objective is not to make policy recommendations at this stage, but just to show preliminary results on potential effects that should be further tested through further research and modelling sophistication.

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List of Abbreviations

CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CNMC	Comisión Nacional de los Mercados y la Competencia
CSP	Concentrated solar power
DGDEM	Dirección general de Política Energética y minas
DMDEG	Direção Geral de Energia e Geologia
EC	European Commission
EEA	European Economic Area
EED	Energy Efficiency Directive
ESD	Effort-sharing Decision
EU ETS	European Union Emissions Trading System
EU	European Union
GDP	Gross domestic product
GHG	Green House Gas
HT	High target
IEA	International Energy Agency
LCOE	Levelized cost of Electricity
LT	Low target
MIBEL	The Iberian electricity market
NREAP	National Renewable Energy Action Plan
O&M	Operation and mainteance
QT	Quata
REE	Red Eléctrica de España
PV	Photovoltaics
UC	Unit-commitment
WEO	World energy outlook

1 Introduction: motivation, objectives and structure

1.1 Motivation

Over the last decade, the European Union has intensified actions towards the achievement of the three core objectives of its energy policy: security of supply, competitiveness and sustainability. Different legislative (Directives; Regulations; Decisions) and strategic initiatives (Communications; Council conclusions; Plans; etc.) have laid down the foundations that currently guide energy and climate policies.

While the EU is making good progress towards meeting its climate and energy targets for 2020 (EC, 2015a), an integrated policy framework 2020 onwards is needed to ensure regulatory certainty for investors and a coordinated approach among Member States (EU, 2014abcd).

In this context, the former European Commission launched two communications in 2014 ("A policy framework for climate and energy in the period from 2020 to 2030"(EC, 2014a) and "Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy"(EC, 2014b)) which set the basis for the 2030 objectives approved by the European Council by the end of 2014(EC): at least 40% greenhouse gas emissions reduction; at least 27% of renewable energy share; at least 27% increasing of energy efficiency and 15% electricity interconnection target.

This 2030 framework is part of a wider strategy presented by the new European Commission as one of its ten priorities, the so-called Energy Union (EC, 2015b). The five mutually-reinforcing and closely interrelated dimensions of Energy Union are: Energy security, solidarity and trust; A fully integrated European energy market; Energy efficiency contributing to moderation of demand; Decarbonizing the economy; Research, Innovation and Competitiveness, which are mutually-reinforcing and closely interrelated.

Now, the focus and the debate is moving from strategy to action, from long-term vision to actual policies and regulations, looking for the most appropriate tools and mechanisms to do it in the most effective, efficient and equitable manner. In this context there is a need for rigorous analyses to help policy makers assessing the different options, anticipating potential impacts, both costs and benefits, as well as uncertainties.

The motivation of this thesis is to contribute to this debate.

1.2 Objectives

As stated above, the motivation of this thesis is to modestly contribute to the debate on the selection of the most appropriate European policies for achieving the EU 2030 energy and climate targets. In order to this, this thesis has two main objectives:

- To develop a simplified model of one of the relevant electricity markets in Europe, the Iberian electricity market (MIBEL), which could be eventually used as a tool for assessing the effects of potential European energy and climate policies in the electricity sector;
- To run a first hypothetical case study with this model in order to test it, and show some of their potential uses when assessing European energy policies

The case study aims to assess potential effects in the Iberian electricity market of different scenarios of CO_2 prices and renewable energy market shares (up to 2030), which are variables that will be affected by the European energy policy that will be developed and implemented in the next years in order to achieve the European 2030 targets.

Notwithstanding, the objective is not to make policy recommendations at this stage, but just to show preliminary results on potential effects that should be further tested through further research and modelling sophistication.

1.3 Structure

The structure of this document is as follows:

- Chapter 2 presents a general overview of the European energy policy framework mainly focusing on the 2020 climate and energy package and the 2030 framework for climate and energy policies.
- Chapter 3 describes the model of the Iberian electricity market developed in this thesis.
- Chapter 4 presents the main characteristics of the scenarios considered for the case study.
- Chapter 5 shows the main results of the case study.
- Finally, Chapter 6 explains main conclusions and proposes future research.

2 European energy and climate strategy

Environmental sustainability is nowadays a global concern that has gained political attention and that is increasingly guiding Governmental decisions in the energy and economic frameworks. Although global community is at the beginning of a long road to travel until sustainable economic growth is reached, encouraging trends can be already appreciated. For example, (i) in 2014, the global economy grew by 3% while carbon dioxide (CO_2) emissions related to energy stayed at the same level being the first time in last 40 years; (ii) in 2014, almost half of the new power generation capacity are renewables, led by growth in China, United States, Japan and Germany, with investment remaining strong (about $270 billion) while costs continuing to fall; (iii) in 2014, the energy intensity of the global economy contracted 2.3%, a result caused by energy efficiency improvement and structural changes in some economies, such as China (IEA, 2015).

Notwithstanding these encouraging trends, the level of commitment towards sustainable growth in different countries is still quite heterogeneous and policy measures still deliver weak signals worldwide. For instance, while around 11% of global energy-related CO_2 emissions arise in areas that operate a carbon market (where the average price is $7 per tonne of CO_2 in 2014), 13% of energy-related CO_2 emissions arise in markets with fossil-fuel consumption subsidies (an incentive equivalent to $115 per tonne of CO_2, on average) (IEA, 2015).

In this evolving context, the European Union has taken a proactive role in the promotion of a low carbon economy and has included the environmental sustainability at the core of its long-term energy strategy as one of the three pillars that must guide energy related actions: environmental sustainability, economic competitiveness and security of supply.

As way to guarantee that specific progress is made in the area of sustainability, the EU has established concrete targets to be reached in 2020, 2030 and 2050 and, more recently, the European Union has positioned decarbonization and efficiency targets at the forefront of the newly formulated European Energy framework: the Energy Union.

This Chapter provides a general background on (i) the internal climate targets set to guide European transition towards a low carbon economy, (ii) the regulatory mechanisms established to guarantee/stimulate that the targets are met; and (iii) on foreseeable level of compliance in the near future with the 2020 targets.

2.1.1 Formulation and approval of 2020 targets

The 2020 climate and energy package has set a 20-20-20 targets which include 3 targets related to “20%” (EC, 2014a): a 20% reduction in GHG emissions compared to 1990; raising the share of EU energy consumption produced from renewable resources to

20%; a 20% improvement in the EU's energy efficiency, these targets are also the most important targets of the Europe 2020 strategy for smart, sustainable and inclusive growth. The EU set the 20-20-20 targets in March 2007 and enacted it in legislation in 2009.

After a number of environmental initiatives and proposals from the EC, the 20-20-20 targets were set independently at different stages attending to different motivations.

- The Commission of "**An Energy Policy for Europe**" (EC, 2007) proposed the European Energy Policy based on an EU goal in international negotiations of 30% reduction in greenhouse gas emissions by 2020 from 1990 levels and an EU unilateral commitment, at least a 20% reduction of greenhouse gases by 2020 compared from 1990 levels. This focused on combating climate change and reducing EU's energy dependence besides boosting internal competitiveness and growth to assure secure and affordable energy to consumers.
- The EU proposed the target to increase the share of renewable energy in the EU's overall mix to 20% by 2020 in the **Renewable Energy Roadmap** (EC, 2006a), following the Green Paper. This is a longer term target for renewable energy considered as continuation of the previous objective (12% of energy consumption from RES by 2010). The promotion of renewable energy is been proceeded as a good way to develop energy production more sustainable and reduce the fuel import dependence. Moreover, the promotion of renewable energy will also push the development of technological innovation and employment across Europe.
- The Commission proposed in **Energy Efficiency Action Plan of 2006** that the target of reducing global primary energy use projections by 20% by 2020. The European Council has also proposed an ambitious program of energy efficiency measures at community, national and international. These aim at lower energy bills, reduce the dependence on fuel imported as well as protect the environment.

2.1.2 Regulatory mechanisms set in place to achieve 2020 targets and foreseeable level of compliance

Many regulatory mechanisms have been set to guarantee the achievement of the 2020 targets and they will be explained in this sector. Moreover, all the Member States are making effort towards these individual climate and energy objectives for 2020.

In 2014, the Commission concluded in its communication (EC, 2014a) that the EU is now well on track to achieve the 2020 targets that to reduce greenhouse gas emissions and to increase the level of renewable energy, meanwhile enormous improvements have been made in the intensity of energy use thanks to more efficient buildings, products, industrial processes and vehicles.

According to this Communication, greenhouse gas emissions have decreased by 18% in 2012 compared to 1990 level and it is expected to reach reduction of 24% and 32% in 2020 and 2030 respectively;13% of the final energy consumption was from renewable energy and it is expected to be 21% in 2020 and 24% in 2020; 44% of installed renewable energy of the whole world is from the EU (EC, 2014a).

2.1.2.1 Carbon reduction target

- **A strengthening of the Emissions Trading System reformation**, directive 2009/29/C21 has amended the previous Directive 2003/87/EC. The Directive 2009/29/C21 came into force in 2013, when the third period of trading started. At present, 11000 more power stations and industrial plants in 31 countries, as well as airlines are covered by the EU ETS (EC, 2015c).

  Instead of national allocating planning from participating countries, a single EU wide cap (reduced by 1.74% each year) on emission allowances will be applied from 2013 and this cap will be lowered annually with a decreasing ratio. The emission allowances are expected to be 21% below the 2005 level in 2020 (EEA, 2014). In the meanwhile, instead of free allocation, auction will become the default method to allocate allowances. The share of allowances to be allocated with auction is more than 40% in 2013 and this number is going to increase yearly (EC, 2015c).

- Under the "Effort-sharing Decision (ESD)"[1], **national targets for emissions from sectors not covered by the EU ETS**, such as transport, housing, agriculture and waste, have been agreed among Member States. The targets are set reflected relative wealth of different Member States and the targets range from 20% reduction for to 20% increase among Member States. The national targets will in total reduce 10% emissions in non-ETS sector by 2020 compared with 2005 level (EC, 2015d).

From the trends and projections in Europe 2015, EEA provides an updated assessment of EU progress towards reaching greenhouse gas emission targets. In 2013, the GHG emissions of EU reduced 19.8% compared to 1990 levels. And the emissions are expected to tail off to levels that around 25% below 1990 levels by 2020 according to national projections reported by Member States in 2015(EEA, 2015). There exist great differences between GHG emissions in ETS sectors and in ESD sectors are due to significantly different trends since 1990 listed below.

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[1] See Directive 406/2009/EC

- In 2014, GHG emissions from Member States' stationary installations covered by the EU ETS reached their lowest level in the past 10 years, at 1786 Mt CO_2 equivalent accounted for a 24% decrease between 2005 and 2014(EEA, 2015). This means that 2014 emissions have also been lower than the 2020 EU ETS target.

- 24 of 28 Member States are on their way to achieve their national GHG targets under the ESD, accounted for around 55% of total GHG emissions at EU level (EEA, 2015). The other 4 Member States (Austria, Belgium, Ireland and Luxembourg) (EEA, 2015) are still with projected ESD GHG emissions higher than the target. Their current policies are considered to be insufficiently effective at overcoming obstacles to lead to enough reduction of emission[2].

2.1.2.2 Renewable Production Target

In order to meet the target of at least 20% of final energy consumption produced by renewables by 2020, the Directive 2009/28/EC51 (EU, 2009) establishes national renewable energy binding targets and a common framework for the promotion of renewables. National binding targets has set the minimum share of gross final energy consumption from RES expected from each Member State in 2020 and the national binding targets range from the lowest RES target of 10% in Malta to highest one of 49% in Sweden. The methodology of sharing the EU level target among each Member State is to use a formula that applies a flat rate increase in the share of renewable energy with taking into account GDP (EU, 2008).

Moreover, cooperation mechanism as an optional provision among Member States to facilitate the renewable energy promotion in order to achieve the target has been proposed by the Commission. Cooperation mechanism is a voluntary measure that could be applied by Member States to help to develop renewable energy out of their countries to count a share of that.

From the assessment from EEA in 2015, the renewable energy consumption keeps growing in 2013, accounted for 15% of the total energy consumption and is getting closer to the 2020 goal. The share in 2013 is above the directive medium-term target set in the Renewable Energy Directive and Member States' national renewable energy action plans (NREAPs) for that year[3]. EEA predicted that if Member States keep the

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[2] For example in case of Luxembourg, a relatively low potential for RES, or economic, such as the low taxes on fuel sales compared to neighboring countries.

[3] In 2013, 25 Member States (i.e. all except Luxembourg, the Netherlands and the United Kingdom) met or exceeded their indicative targets for 2013 to 2014 set under the RED, while 21 Member States (i.e. all except Denmark, France, Ireland, Luxembourg, the Netherlands, Portugal and Spain) exceeded the indicative trajectories set in their national action plans. (EEA, 2015)

current speed of development Renewable energy, the 2020 target could be achieved at that time.

2.1.2.3 Efficiency target

Following some of the recommendations made in the Communication on an Energy Efficiency Plan 2011[4], Directive 2012/27/EU[5] on energy efficiency was adopted by the EU in October, 2012. In this Directive, a common framework of measures for the promotion of energy efficiency in the EU has been established to guide to achieve the 20% energy efficiency target. The Directive suggested actions to increase energy efficiency on buildings, transport and products and processes.

Currently the primary energy targets taken on Member States under the Energy efficiency directive (EED) has been consider as lack of ambition. The sum of the latest primary energy consumption targets from all Member States remains 3% higher than the EU targets (EEA, 2015), which means that if all the Member States only achieve their primary national targets, it will be unable to meet the primary energy target.

For some Member States, There is much room for them to increase their renewable energy consumption compared to the 2020 targets. In the EED, it's not stated manifestly, however all the Member States can adjust their final 2020 targets in the year-end summary reports or in the NEEAPs. At the end of 2014, up to 12 Member States (Austria, Bulgaria, Croatia, Cyprus, France, Greece, Italy, Poland, Slovakia, Spain, Sweden and the United Kingdom) revised their final 2020 targets in the NEEAPs (EEA, 2015). Among these countries, 9 countries set more radical targets according to their analysis on the impact of the economic crisis on their economies. On the contrary, Bulgaria, Slovakia and Poland reduced their final targets, it means that compare to their original targets set in 2013, they will have higher energy consumption levels by 2020 (EEA, 2015).

2.2 The 2030 climate and energy framework: New targets, Energy Union and debate on possible ways to structure goals' achievement

In order to keep pursuing a competitive, secure and sustainable economy and energy system, as well as a new target is needed after 2020, the EU Commission proposed the 2030 policy framework in January 2014. It also meets the need for integrated policy framework for the period up to 2030 to ensure regulatory certainty for investors and a coordinated approach among Member States.

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[4] COM (2011) 109 of 8 March 2011, which is made after assessing that actions taken in the EU would only result in half achievement of the target on energy efficiency.

[5] Directive 2012/27/EU of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

The 2030 climate and energy framework is in line with the longer term perspective set out in the Roadmap for moving to a competitive low carbon economy in 2050, the Energy Roadmap 2050 and the Transport White Paper.

Additionally, the 2030 climate and energy framework has been embedded into the new Energy framework set after the change of presidency in the European Commission.

2.2.1 Formulation and adoption of 2030 targets

The European Commission launched two communications in 2014 which set the basis for the 2030 objectives approved by the European Council by the end of 2014: at least 40% greenhouse gas emissions reduction; at least 27% of renewable energy share; at least 27% increasing of energy efficiency and 15% electricity interconnection target.

The proposal of GHG emission reduction target from the Commission is to delivery 40% in domestic EU level shared together by both ETS and non-ETS sectors while the current policies and measures are still need to be implemented by Member States until 2020. The target for ETS sector would have to be 43% reduction while 30% for non-ETS reduction both comparing with emission in 2005. For the ETS sector, the annual factor, used to limit the maximum emissions is needed to decrease more dramatically (from 1.7% to 2.2%) since 2020 to achieve the target. And for non-ETS sector, the allocation of the effort depends on GDP per capita which represents the relative wealth of different Member States. According to the close interconnection between GHG emissions and increasing sharing of renewable energy, the target of 27% share of renewable energy is set since it´s the minimum level accompanying with the 40% greenhouse gas reduction target.

- The new renewable target is different with the one of 2020 targets because it only has an EU level binding target without specific national level targets. At the same time, a new governance framework is needed to ensure the achievement of the European target. In addition, the Directive on renewable sources may be revised after 2020 in order to provide tools to ensure the achievement of 2030 targets. Biomass policy is also needed to be improved to solve relative issues such as maximizing the resource efficient use of biomass, fair competition among different types of uses of biomass resources and etc.

- The EU target for energy efficiency is not binding and the progress is being delivered by specific policy measures at Union and national levels including for domestic and industrial appliances, vehicles, and for the building stock.

This 2030 framework is part of a wider strategy presented by the new European Commission as one of its ten priorities, the so-called Energy Union (EC, 2015b). The five mutually-reinforcing and closely interrelated dimensions of Energy Union are: Energy security, solidarity and trust; A fully integrated European energy market; Energy efficiency contributing to moderation of demand; Decarbonizing the economy; Research, Innovation and Competitiveness, which are mutually-reinforcing and closely interrelated.

2.2.2 Debate on regulatory measures and mechanisms to meet renewable 2030 target

Now, the focus and the debate is moving from strategy to action, from long-term vision to actual policies and regulations, looking for the most appropriate tools and mechanisms to do it in the most effective, efficient and equitable manner. In this context there is a need for rigorous analyses to help policy makers assessing the different options, anticipating potential impacts, both costs and benefits, as well as uncertainties.

Even though the foundation has been laid by the 2030 framework, there are still some open issues needed to be tackled: e.g. the governance and allocation of the effort between Member States.

Targets binding at national level

As mentioned before, the new renewable target of 2030 only has an EU level binding target without specific national level targets. Binding at the EU level could bring more flexibility to the whole Member States so they can choose the most cost-efficient way to achieve the target based on their own circumstances, energy generation mix, capacities and etc. However several open questions that need to be solved: e.g. how to ensure the final achievement of the EU-target under the condition of lacking binding national commitments and how to allocate the overall 27% target among each Member State or groups of Member States (Anne Held, et al., 2014).

Bottom up vs. top down target determination

In principle, two approaches exist to allocate the EU-wide target to single Member State or groups of Member States: top-down or bottom-up approach. The EU may need to compare the pros and cons in order to choose one of them in order to lead an efficient way to achieve the 2030 targets.

The top-down approach will need transparent criteria, such as the 2020 target sharing logic which laid down in Directive 2009/28/EC (Anne Held, et al., 2014). Besides a flat-rate increase for every Member States plus considering the economic strength measured in terms of GDP per capita used in allocation of 2020 target, other aspects such as efforts made in the past and the past effort has been made by Member States and renewable energy potentials are also very good options.

The latter case may lead to a gap between summed up pledges of Member States and the overall targets of 27%. Then pledge iterations or financing mechanisms may be required to close the gap. To avoid this situation, a benchmark with Member State or regional level targets should be given by the EU in advance in order to guide constructing the process of pledge and to avoid extremely low pledges at the beginning (Anne Held, et al., 2014).

Regional cooperation

Regional cooperation has been created to give the possibility to improve the economic efficiency of renewable energy target compliance in the EU. Through regional cooperation, the EU also seeks to maximize cross-border benefits, including balancing options, to increase flexibility in the energy system and to help plan supply and infrastructure in a more integrated and synchronized way (Ecofys, 2015).

Challenges arising from regional cooperation also exist, such as “risk of tensions between different regional approaches” [6] (De Jong and Egenhofer, 2014). It also rightly points at potential governance issues: regional cooperation, especially in geographically overlapping regions, can result in overlapping competencies between those regions, Member States and the Comission.

Besides the modeling part of this thesis, it will focus on the RES target and explain possible design options that may be considered regarding effort sharing of this target.

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[6] Regional cooperation can potentially result in policy fragmentation if policies developed in one region are not compatible with policies developed in another region.

3 Modeling the Iberian day-ahead electricity market

One of the main focuses in this master thesis is to model the Iberian Day-ahead market properly in order to assess possible effects of European 2030 energy targets on the results of the Iberian electricity market. In this chapter, the details of the model are described, including the assumptions applied to the model, the objective functions, the main constraints and the input data explanation.

3.1 Model overview

In this thesis, a deterministic linear optimization problem has been formulated to compute the minimum cost dispatch of the Iberian power system in a set of different scenarios. Results of this model (optimal production schedules and resulting market prices) can be used to evaluate possible impacts of energy policy affecting, for example, demand, generation capacity mix or carbon prices.

A one-year scope and chronological hourly demand has been used in the simulations, thus combining the short-term operation details of Unit-Commitment (UC) together with a medium-term horizon scope. This two-fold goal has been approached using integer variables to track commitment status of units rather than the UC binary variables approach, reducing the computational burden of the problem; see (Palmintier and Webster, 2014) for further details.

The central planner's solution that this formulation provides is equivalent to the one resulting of a market equilibrium approach under the assumption of perfect competition (Mariano Ventosa, 2013).

Total system dispatch costs modeled include: units fuel cost, CO_2 emission cost, operation and maintenance (O&M) cost, start-up cost and taxes.

Main constraints in this model include the generation-demand balance, limits on hydro and pumping production, specific technology limitations and interconnection limits.

Eleven types of technologies have been represented including nuclear units, thermal units, large hydro, pumping storage, and technologies under regulation retribution schemes[7].

Nuclear, coal and CCGT units have been modeled under similar technical constraints of maximum and minimum power output and logical start-up and shut-down constraint. Additionally, nuclear units have been considered as must-run units.

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[7] From July 2013, the Spanish Government has undertaken a reform of the Renewal sector by approving the following pieces of legislation: Royal Decree-law ("RDL 9/2013"), The Electricity Sector Act (the "Law 24/2013"), Royal Decree Law (RDL 431/2014) and Ministerial order IET/1045/2014, MO 1045/2014.

Hydro production in ordinary regime has been modeled distinguishing between large hydro and pumping storage. Mixed pumping storage capacity has been split ad-hoc under the assumption that part of this capacity behaves as large hydro and part as pure pumping storage; real historical data has been used to set this proportion. Large hydro has been modeled accounting for dispatchable and non-dispatchable production (run of river); real historical data has been used to determine minimum monthly output of large hydro accounting for non-dispatchable production. See Figure 1.

Figure 1: hydro units modeling structure
Source: Own elaboration

Production of technologies under special regime is an input to the model, which is derived from annual production (calculated based on estimated installed capacity and the equivalent working hours from historical data) and hourly profile (wind, solar PV and CSP profiles used are based on historical data; small hydro and thermal production under special regime has been set to maintain a flat profile).

A spillage constraint has been modeled accounting for situations in which demand is lower than the production from technologies under special regime and must-run units. At these hours, the model is set to reduce the production of these technologies to meet demand. The reduction is in first place from the production of CSP, thermal under special regime, and then, if necessary, from small hydro, wind and PV solar.

The interconnection between Spain and Portugal has been modeled so that flows between these two countries are endogenously determined. Interconnection flows between MIBEL and France, Morocco and Baleares have been exogenously calculated based on historical data and maintained fixed throughout the period under a flat hourly profile.

3.2 Model statements

3.2.1 Notations

Symbols used in this section are divided into three categories: sets, parameters and variables, following GAMS formulation.

Sets

n: set of generation groups in the system

- *th:* thermal and nuclear generation groups, subset of set *n*
- *hd:* dispatchable hydro generation group, subset of set n
- *hr:* run-of-river hydro generation group, subset of set n
- hy: big hydro generation groups, union of set *hd and hr*
- *hb:* hydro pumping storage generation groups, subset of set *n*
- *nd:* generation groups[8] under special regime, subset of set *n*
  - *nd1:* CSP group, thermal renewables group and thermal non-renewables group, which are given in the model lower priority to maintain their production once spillages occur, subset of set *nd*
  - *nd2*: Mini hydro group, wind group and PV solar group, which are given in the model higher priority to maintain their production once spillages occur, subset of set *nd*

mon: set of months

h: set of hours

c: set of sub-markets within Iberian electricity market (i.e. c, Spanish market; p, Portuguese market)

Parameters:

$dm_{h,c}$: hourly busbar demand profile[%]

ad_c: annual busbar consumption demand of each market [MWh]

$xm_{h,c}$: hourly energy exports profile to third countries [%]

aep_c: net annual exports from each sub-market to third countries [MWh]

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[8] Capacity under special regime is divided in seven technologies, namely wind, solar PV, CSP, mini Hydro, thermal renewable and thermal non-renewables.

su_{th}: start-up cost of nuclear and thermal plants [euros/h]

$varcost_{th}$: variable cost of nuclear and thermal generation plants [euros/MWh]

fit_{th}: fixed-term cost of nuclear and thermal plants [euros/h]

p_{nes} : non-served energy cost [euros/MWh]

$qmin_{th}$: minimum generation plant production of each group[9] [MW]

$qmax_{th}$: generation plant installed capacity of each group[10] [MW]

$\mathrm{qMIN}_{\mathrm{n}}$: minimum generation capacity of each generation group [MW]

$\mathrm{qMAX}_{\mathrm{n}}$: maximum generation capacity of each generation group [MW]

$\mathrm{bmax}_{\mathrm{hb}}$: maximum pumping capacity [MW]

$wmin_{hb}$: minimum storage energy in reservoir generation units [MWh]

$wxmax_{hb}$: maximum storage energy in reservoir generation units [MWh]

af_{n}: available factor of each group[11] [p.u.]

nog_{th}: number of generation plants within each group [number]

$rend_{hb}$: efficiency of the pumping-turbine cycle of pumping storage generation units [p.u.]

$hmp_{mon,hd}$: monthly maximum accumulated production of big hydro generation units [MWh]

$hmc_{mon,hb}$: monthly maximum accumulated consumption of pumping storage generation units [MWh]hdm_{h}: hourly maximum power output of big hydro units [MWh]

$mhr_{mon,hr}$: hourly run-of-river flow within different month [MWh]

$\mathrm{patn}_{h,\ nd}$: hourly production profile of technologies under special regime [p.u.]

$apnd_{nd}$: annual production of each non-dispatchable technology [MWh]

limex: Maximum power exchange between Spanish market and Portuguese market [MW]

uo_{th}: the initial on-off status of nuclear and thermal generation groups [number]

winit: pumping storage units initial stored energy [MWh]

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[9] All the generation plants within the same group share the same minimum production.

[10] All the generation plants within the same group share the same installed capacity.

[11] All the generation plants within the same group share the same available factor.

Variables

$q_{h,n}$: production of group *n* at hour *h* [MWh]

$b_{h,hb}$: pumping-storage consumption of group *hb* at hour *h* [MWh]

$w_{h,hb}$: hydro pumping energy reserve level of group *hb* at the beginning of each hour h [MWh]

qsp_h: energy flow from Spain to Portugal at hour *h* [MWh]

qps_h: energy flow from Portugal to Spain at hour *h* [MWh]

$nse_{h,c}$: non-served energy at hour *h* in each sub-market [MWh]

$spill_{h,c}$: Spillages from technologies under special regime during hour *h* in each sub-market [MW]

$ISU_{h,th}$: number of units that are going to be started up in group *th* at the beginning of hour *h*

$ISD_{h,th}$: number of units that are going to shut down in group *th* at the beginning of hour *h*

Integer Variables

$MIO_{h,th}$: number of units in group *th* that are on at the beginning of hour *h*

3.2.2 Objective function

The objective function of this model is the total generating costs, including variable costs, start-up costs, no-load costs and non-served energy costs.

Variable costs are composited by fuel cost, O&M cost, CO_2 emission cost and tax. Detailed description of how variable costs haven been calculated is provided in chapter 3.3.3. For the specific case of hydro units and units applying technologies under special regime, null producing costs have been assumed.

Start-up costs represent fuel expenditure needed to reach a suitable boiler pressure and temperature. In this model simplified constant costs (su_{th}) have been considered. Start-up costs of each group at each hour equal to constant start-up cost of one plant times the number of plants within this group that are decided to start up.

No-load costs it's a euro per hour rate accounting for the expenditure of fuel to maintain the necessary function of plants.

Non-served energy costs equals non-served energy price times the quantity of non-served energy, which is introduced in the model in order to avoid infeasibility when it is physically impossible to satisfy the demand.

$$\textit{Minimizing}$$
$$\sum_{th}\sum_{h} VarCost_{th} \cdot q_{h,th} + \sum_{th}\sum_{h}(su_{th} \cdot ISU_{h,th} + fit_{th} \cdot MIO_{h,th}) + \sum_{c}\sum_{h} pnes \cdot nse_{h,c}$$

3.2.3 Constraints

Demand balancing constraint

At each hour, for both Spanish part and Portuguese part, the sum of energy produced by the domestic generation units (it may include a spillage) plus energy imported from other countries minus energy exported to other countries must equal demand. In order to account for the situation with not enough installed capacity in the system and to make sure even under this case the model runs properly, a variable of non-served energy in each system with an extremely high penalty cost has been introduced.

$$\sum_{th \in s} q_{h,th} + \sum_{hy \in s} q_{h,hy} + \sum_{hb \in s}(q_{h,hb} - b_{h,hb}) + \sum_{nd \in s} q_{h,nd} - spill_{h,s} - qsp_h + qps_h + nse_{h,s} = dm_{h,s} \cdot ad_s + aep_{h,s} \cdot ax_s \quad \forall h$$
$$\sum_{th \in p} q_{h,th} + \sum_{hy \in p} q_{h,hy} + \sum_{hb \in p}(q_{h,hb} - b_{h,hb}) + \sum_{nd \in p} q_{h,nd} - spill_{h,p} + qsp_h - qps_h + nse_{h,p} = dm_{h,p} \cdot ad_p + aep_{h,p} \cdot ax_p \quad \forall h$$

Interconnection constraint

An interconnection has also been considered in the model, power exchange between Spanish market and Portuguese market is considered as a variable, while power exchange between MIBEL and other power systems is given as inputs to the model. The power exchange variable has been introduced in the demand balancing constraint considering that the power exchange amount should be lower than the maximum interconnection capacity.

As we do not consider the transmission cost and losses during the energy exchange, these two sub-markets share the same market price when there is no congestion between them. On the other situation, when there is congestion between two sub-markets, the market will split into two independent markets and they are going to have different prices. Namely, the dual variables of demand balancing constraints are the same when the power exchange in less than the interconnection limitation, and are different when the limitation is reached.

$$qsp_h \le limex \qquad \forall h$$

$$qps_h \text{ £ } limex \qquad \text{"}\ h$$

Constraints for nuclear, coal and CCGT units

1. Logical constraint of start-up and shut-down decisions

In order to simplify the model, reduce the processing time, and take advantage of the data structure designed previously, integer variables have been used to formulate the start-up decision. The corresponding logical constraint of the start-up and shut-down decision is shown below:

$$MIO_{h,th} = MIO_{h-1.th} + ISU_{h,th} - ISD_{h,th} \quad \forall th, \forall h > 1$$
$$MIO_{1,th} = uo_{th} + ISU_{1,th} - ISD_{1,th} \quad \forall th$$

In this model, the clustered unit commitment method is used to formulate the constraint of start-up and shut-down decisions following a similar approach to (Palmintier and Webster, 2014).). As mentioned in their work, the reason to substitute the traditional unit commitment method is that the combination of too many binary variables (representing on/off decisions and one per each unit per time) makes the problem solving very complicated.

2. Nuclear units as must-run units constraint and maximum and minimum production constraints

Nuclear, coal and CCGT units can only produce power below their maximum capacity and above their minimum limitation. In the model, every generation plant has its maximum and minimum production constraints. The maximum output capacity is determined by the nominal power of the generation plant while the minimum capacity is determined by the minimum output at which the generation plant reaches the stable combustion stability requirement, in the case of thermal units.

For thermal generation group, the number of units that are on is always lower or equal to the total number within this group.

$$MIO_{th} \leq nog_{th} \qquad \forall th$$

In the case of nuclear plants, a relative high minimum production has been set in the model since nuclear power plants are normally operated continually at full capacity due to low variable costs and little operating flexibility. Nuclear generation units are considered as must-run units in the model. It is represented by setting the number of units that are on in nuclear groups (MIN_{th}) always equals to the number of units within this group (nog_{th}).

$$MIO_{th} = nog_{th} \quad \forall th = nuclear$$

In order to consider the availability of generation units, we have taken into account the availability factor representing the duration that certain unit is available to generate electricity over specific period, divided by the whole duration of that period. So the maximum production of each group will depend on the corresponding maximum capacity, availability factor and the number of machines that are on during that hour:

$$MIO_{h,th} \cdot qMIN_{th} \leq q_{h,th} \leq MIO_{h,th} \cdot qMAX_{th} \cdot af_{th} \quad \forall th,h$$

Hydro units constraints

Hydroelectric facilities are generally located in natural river beds. So it must be taken into account that the entire flow released by a reservoir situated at the top of a chain reaches the plants located downstream after a certain leg time. In this study we have simplified the way to model hydro units since considering these hydro units in detail will raise a very complex problem, which falls outside the bound of this study. Consequently, an aggregated model is used for both big hydro units and pumping storage units in each sub-market in line with their different behaviors and characteristics.

Since the nature flows of mixed pumping storage units are difficult to obtain and it may differ for every single facility, an assumption has been made that part of mixed pumping storage capacity behaves as big hydro units and the rest as pure pumping storage units, explained in detail in Annex 1. Thus, input data of installed capacity of each category of hydro generation units finally entering into the model equals to the real value, plus an extra part from mixed pumping storage equivalence.

1. Constraints for big hydro units

Big hydro units production ($q_{h,hy}$) consists of two parts, dispatchable part ($q_{h,hd}$) and run-of-river part ($q_{h,hr}$).

$$q_{h,hy} = q_{h,hd} + q_{h,hr} \quad \forall h$$

Dispatchable part are used to model regulating plants that have a reservoir to store water and can consequently manage the storage over certain period. Water management horizon in this model is monthly regulation. For each month, big hydro units have a maximum energy production limitation ($hmp_{mon,,hd}$), which represents the maximum accumulated monthly energy production.

$$\sum_{h\in mon} q_{h,hd} \leq hmp_{mon,hd} \quad \forall hd, mon$$

Power output is limited by the maximum capacity.

$$q_{h,hd} \leq qMAX_{hd} \quad \forall h, hd$$

On the contrary since run-of-river part doesn't hold any ability to store energy, the entire flow must be converted to power or emptied into the river in real-time.

$$q_{h,hr} \leq mhr_{mon,hr} \ \forall hr, mon, h \in mon$$

2. Constraints for hydro pumping storage units

All pumping storage units must maintain the reservoir evolution at each hour. Each reservoir has its own capacity and the amount of water in the reservoir at any time should be within that range considering that energy stored at the end of hour *h* is the amount existing at the end of the previous hour *h*-1, less production ($q_{h,hb}$) plus the energy coming from pumping ($rend_{hb} \cdot b_{h,hb}$):

$$w_{h,hb} = w_{h-1,hb} - q_{h,hb} + rend_{hb} \cdot b_{h,hb} \forall h, hb$$

Power stored in reservoirs has its upper and lower bound ($wmin_{hb}$, $wxmax_{hb}$).

$$wmin_{hb} \leq w_{h,hb} \leq wmax_{hb}$$

It is also necessary to set a guideline value (*winit*) for pumping storage units, which is used to determine the power amount that pumping storage units could consume during certain month. The model will find an optimization decision to allocate water in order to minimize the total cost.

$$w_{h,hb} = winit \quad \forall h \in (744,1416,2160...8760)$$

Similar to the monthly maximum energy production ($hmc_{mon,hb}$) constraint of big hydro units, accumulated monthly maximum consumption constraint has been modeled as well.

$$\sum_{h\in mon} b_{h,hb} \leq hmc_{mon,hb} \forall mon, hb$$

Power output is limited by the maximum capacity:

$$q_{h,hb} \leq qMAX_{hb} \quad \forall h, hb$$

Pumping capacity is likewise limited to nominal capacity

$$b_{h,hb} \le bmax_{hb} \quad \forall h, hb$$

Constraints applying to units with incentivized production under regulation retribution schemes

The production of incentivized generating technologies is determined by hourly profile (*patn*$_{h,nd}$) and annual energy production (*apnd*$_{nd}$).

As mentioned before, when demand is lower than the sum of minimum production of nuclear units plus the production from generation plants under special regime, the system is going to reduce the production of these units in order to maintain the generation-demand balance.

In this case, the model calculates this reduction in production (*spll*$_{h,c}$), and reduces firstly energy generated by CSP, thermal renewable and thermal non-renewable since these are more manageable technologies than the others. In case that the generation-demand balance is still not fulfilled, the model will continue reducing energy generated from wind, small hydro, PV solar and run-of-river units.

$$q_{h,nd} = patn_{h,nd} \cdot apnd_{nd} \quad \text{if} \, spill_{h,c} = 0 \quad \forall h, c, nd \in c$$

$$\left.\begin{array}{c} q_{h,nd1} = \dfrac{pant_{h,nd1} \cdot apnd_{nd1}}{\sum\limits_{nd1} patn_{h,nd1} \cdot apnd_{nd1}} \cdot \left(\sum\limits_{nd1} patn_{h,nd1} \cdot apnd_{nd1} - spll_{h,c}\right) \\ q_{h,nd2} = patn_{h,nd2} \cdot c_{nd2} \end{array}\right\}$$

$$\text{if } 0 < spill \le \sum_{nd1} patn_{h,nd1} \cdot apnd_{nd1} \quad \forall h, c, nd1 \in c, nd2 \in c$$

$$\left.\begin{array}{c} q_{h,nd1} = 0 \\ q_{h,nd2} = \dfrac{pant_{h,nd2} \cdot apnd_{nd2}}{\sum\limits_{nd1} patn_{h,nd2} \cdot apnd_{nd2}} \cdot \left(\sum\limits_{nd1} patn_{h,nd1} \cdot apnd_{nd1} + \sum\limits_{nd2} patn_{h,nd2} \cdot apnd_{nd2} - spll_{h,c}\right) \end{array}\right\}$$

$$\text{if } \sum_{nd1} patn_{h,nd1} \cdot qapnd_{nd1} < spill \le \sum_{nd1} patn_{h,nd1} \cdot apnd_{nd1} + \sum_{nd2} patn_{h,nd2} \cdot apnd_{nd2}$$

$$\forall h, c, nd1 \in c, nd2 \in c$$

3.3 Inputs

In this section, the input data that has been used in the model is presented. This section is divided into the following parts: (i) description of hypothesis made regarding future demand estimation and interconnection flows; (ii) explanation of assumptions made about future generating capacity and input data used to reproduce productions patterns and constraints affecting some technologies and (iii) description of input data used to model future electricity producing costs.

It must be taken into account that input data described in this chapter refers to a Reference Scenario. Notwithstanding, sensibility analysis will be performed to evaluate possible impacts of European energy targets with respect to this Reference Scenario. Input data used in the formulation of additional scenarios is described in Chapter 4.2-4.4 of this Thesis.

3.3.1 Expected demand and interconnection flows

In the Spanish case, peninsular annual net demand is estimated to reach 251.6 TWh in 2015 according to General Direction of Energy Policy and Mines (DGPEM, 2014). For 2020, demand prediction has been taken out from the report published by the Regulator (CNMC) analyzing Governmental proposal for the development of the electricity networks up to 2020.[12] In this report, CNMC predicted a demand growth rate from 2015 to 2017 equal to 1.7% (a lower number than the one considered by the Government, mainly due to an estimated slower recovery from the economic crisis) while from 2017 to 2020 the predicted demand growth rate increases to 2% (CNMC, 2015). Due to lack of demand prediction of Spanish electricity market 2020 onwards, for the period 2020-2030, it has been assumed an annual demand growth of 2% following the growth trend envisaged for the last years of the previous decade. The more growth part of demand could be compensated by the technologies development and efficiency improvement is been assumed.

In the Portuguese case, the General Direction of Energy and Geology (GDEG) estimates annual increases of national demand between 0.8% - 1.4% for the period 2012-2030 (GDEG, 2013). These estimations take into account possible impacts of energy efficiency targets according to NREAP and possible effects of the introduction of electric vehicles into the system. In this master thesis, the central scenario for demand estimation from GDEG has been assumed.

Table 1 shows the demand estimation up to 2030 that are used as input data in this model.

	Peninsular Spanish Demand	Portuguese Demand
2015	251.6	48.8
2020	273.7	53.6
2030	333.7	58.8

Table 1: Demand estimation up to 2030 (TWh)
Source: GDEPM, CNMC, GDEG

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[12] Informe sobre la propuesta de planificación de la red de transporte de energía eléctrica 2015-2020

As it was mentioned before, international exchanges within the Iberian electricity market (i.e. energy flows between Spain and Portugal) are calculated endogenously in the model. However, energy international exchanges with other regions are inputs calculated from historical data. Table 2 shows annual energy net imports of Spain with other regions.[13]

In this table, it can be seen that annual exports from Spain to Morocco and Andorra have maintained quite a regular pattern along the period 2011-2014, and so, it has been assumed a similar future behavior in the model.

On the counterpart, energy exchanges with France in the past have shown significant variations among different years and future planned extensions may affect significantly the value of net annual exchanges. However, the estimation of future behavior of the Spanish interconnection with France would require detail specific analysis that is out of the scope of this master thesis. In this regard, for the sake of simplicity, it has been assumed a net balance of the interconnection flows equal to the average of annual net balances in the past 4 years, being the modeling of this interconnection a future area of work to expand the analysis included in this Master Thesis.

Finally, from 2012, the Balearic HVDC Link connects the Spanish power system with the Balearic Islands'. The net balance of this interconnector has kept stable in 2013 and 2014 and so, future net power exchanges with Balearic Islands has been assumed to remain equal to 2014 results.

Balance	2011	2012	2013	2014	Assumptions 2015-2030
Balearic HVDC Link	0.00	-0.40	-1.30	-1.30	-1.30
France Balance	1.50	1.90	1.70	3.60	2.18
Morocco Balance	-4.60	-5.00	-5.50	-6.00	-5.28
Andorra Balance	-0.30	-0.30	-0.30	-0.20	-0.28
Total balance with third regions	-3.40	-3.80	-5.40	-3.90	-4.68

Table 2: Annual Energy balance in Spain (TWh), years 2011-2014
Source: esios

3.3.2 Future generation capacity and production patterns

3.3.2.1 Nuclear and thermal units

For modeling purposes, all the generation units have been aggregated into groups with the same technology that share the same variable costs and performance ratios (efficiency, availability, carbon emission factor, etc.). All units in the same group are

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[13] Source: esios, P48 inter-annual energy balance (MWh). Years 2011 – 2014.

assumed to have the same installed capacity which equals to the average installed capacity of the units included in that group.

In the Spanish power system it has been distinguished among national coal plants, international coal plants, CCGT plants and nuclear plants, while in the Portuguese system, it has just been distinguished between coal and gas plants since the last fuel oil plant was decommissioned in 2014.

Next, a description and justification of how the different units within each technology have been grouped is presented explaining also assumptions regarding future installed capacity in each group.

Spanish national coal technology refers to all the units that participated until 2015 in the Security of Supply Mechanism regulated by the Royal Decree 134/2010. Units of this technology have been divided for modeling purposes into four groups (NC1, NC2, NC3 and NC4) according to their recognized variable costs for 2014.[14] Table 3 shows the units included in each group and their recognized variable cost in the past.

Group	Unit name	Recognized variable cost
NC1	Teruel	41.13
NC2	Soto de Ribera 3	44.32
NC2	La Robla 2	45.4
NC2	Narcea 3	46.31
NC2	Compostilla	47.59
NC3	Anllares	50.33
NC3	Guardo 2	52.17
NC4	Puentenuevo 3	54.88
NC4	Elcogás	55.2

Table 3: Group information of plants consuming national coal in Spanish market
Source: BOE 2013

Most of the domestic coal unit is assumed not to enter the Transitional National Plan and therefore their running hours are assumed to be limited to 17.500 from 2016 to

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[14] “Resolución de 30 de diciembre de 2013, de la Secretaría de Estado de Energía, por la que se fijan las cantidades de carbón, el volumen máximo de producción y los precios de retribución de la energía, para el año 2014, a aplicar en el proceso de resolución de restricciones por garantía de suministro” and “Corrección de errores de la Resolución de 30 de diciembre de 2013, de la Secretaría de Estado de Energía, por la que se fijan las cantidades de carbón, el volumen máximo de producción y los precios de retribución de la energía, para el año 2014, a aplicar en el proceso de resolución de restricciones por garantía de suministro”

2023. As these plants reach this limit, they are supposed to be decommissioned. Accordingly, in the model it is assumed that plants that do not enter the Transitional National will be decommissioned after 2020 in line with Government estimations for the planning of electricity networks deployment (CNMC, 2015). It is assumed that all the units in group NC4 will meet the running hour limit so they will be decommissioned after 2020. The table below shows the estimated national coal groups' installed capacity in 2015, 2020 and 2030.

	2015	2020	2030
NC1	1056	1056	1056
NC2	2191	2191	2191
NC3	689.3	689.3	689.3
NC4	596.2	0	0

Table 4: Estimated coal plants installed capacity (MW) by group
Source: CNMC, Own elaboration

group	unit	Full load equivalent hours (2014)
I1	Narcea 1	0
I1	Guardo 1	620
I1	Narcea 2	1082
I1	Soto de la Ribera 2	2975
I1	La Robla 1	3076
I2	Lada 4	4616
I2	Puentes 4	4857
I2	Meirama	5522
I2	Litoral de Almería 2	5559
I2	Aboño 1	6116
I2	Puentes 3	6321
I2	Puentes 2	6641
I2	Puentes 1	6883
I2	Los Barrios	7647
I2	Litoral de Almería 1	7996
I2	Aboño 2	8071

Table 5: group information of plants consuming international coal in Spanish market
Source: REE 2015

International coal technology in Spain includes 18 units adding up 5694 MW. Units of this technology have been divided into two groups (IC1 and IC2) according to their past working hours which can be seen in Table 5. Units with lower number of hours in operation are modeled with lower efficiencies and consequently they will present higher variable costs. It has been assumed Narcea 1 and Guardo 1 in group IC1 do not enter the Transitional National Plan due to their high variable costs. The estimated installed capacity of international coal plant groups is shown in Table 6.

	2015	2020	2030
IC1	851	657	657
IC2	4843	4843	4843

Table 6: Estimated installed capacity (MW) of international coal plant groups
Source: CNMC

Spanish CCGT plants have been classified into three groups according to their production levels in the past. Units with higher production levels are assumed to have lower variable costs due to their access to more advantageous natural gas prices. On the opposite side, units that have barely operated on the last years are assumed to have higher fuel costs. Plants with intermediate operating levels are assumed to present natural gas costs between those estimated for the two aforementioned groups.

According to the proposal of “Development of electricity transmission network 2015-2020”, issued by DGPEM in 2014, there is no new investment on CCGT plants. In addition, due to current overcapacity in the Spanish power system and according to announced legislation, a mothballed capacity of 6000 MW CCGT started from 2015 in line with CNMC predictions is assumed. Among this capacity of mothballing, 2.000-3.000 installed capacity of CCGT will be out of the market according to already submitted closure requests as predicted by the CNMC (CNMC, 2015). In the model, it is assumed that in total 3042 MW of CCGT plants will come back into the system during 2020-2030 after their mothballing taking into account predicted demand evolution. Additionally, it has been estimated that new capacity may need to enter the system before 2030 to maintain adequate firmness levels in some scenarios (see Chapter 5.2). In the Reference Scenario, however no new capacity requirements are envisaged.

Group	Unit	Full load equivalent hours (2014)
CCGT1	Aceca 4	3301
CCGT1	Bahia Bizcaya	7862
CCGT1	Besós 4	7584
CCGT1	Besós 5	3132
CCGT1	Cartagena 3	3319
CCGT1	Málaga 1 CC	5813
CCGT1	Puerto de Barcelona 1	4159
CCGT1	Sabón 3	3118
CCGT1	Sagunto 2	3443
CCGT1	Sagunto 3	3497
CCGT1	San Roque 1	6881
CCGT1	Cartagena 1	2694
CCGT1	Palos 3	2503
CCGT1	Puerto de Barcelona 2	2735
CCGT1	Cartagena 2	2083
CCGT1	Castellón 4	2384
CCGT1	Plana del Vent 2	1826
CCGT2	Palos 1	1248
CCGT2	Puentes Gcía. Rguez. 5	1309
CCGT2	San Roque 2	1229
CCGT2	Tarragona Power	1101
CCGT2	Aceca 3	965
CCGT2	Besós 3	833
CCGT2	Castejón 1	966
CCGT2	Colón 4	801
CCGT2	Plana del Vent 1	990
CCGT2	Soto de la Ribera 4	943
CCGT2	Amorebieta	610
CCGT2	Arcos 3	539
CCGT2	Arrúbal 1	784
CCGT2	Arrúbal 2	590
CCGT2	Campo de Gibraltar 1	669
CCGT2	Campo de Gibraltar 2	706
CCGT2	Castejón 3	614
CCGT2	Castelnou	518
CCGT2	Sagunto 1	535
CCGT3	Castellón 3	210
CCGT3	El Fangal 3	189
CCGT3	Soto de la Ribera 5	317

Table 7: List of CCGT group with units and working hours Source REE 2015

Nuclear capacity in the Spanish system is maintained for the time horizon of the analysis in line with the predictions by DGPEM (2015), shown in the table below.

	2015	2020	2030
Nuclear group (MW)	7572.58	7572.58	7572.58

Table 8: Estimated nuclear group installed capacity
Source: DGPEM

In the Portuguese case, regarding thermal generation facilities under ordinary regime, two big changes are expected: (i) for coal plants, the decommissioning of Coal plant Sines is scheduled at the end of 2017 and the decommissioning of Coal Plant Pego is scheduled at the end of 2021, so that thermal power generation system of continental Portugal will be totally dependent on a single source of fossil fuel, natural gas from then on; (ii) two new CCGT plants (415 MW for each) will enter the power system to guarantee the reliability of energy supply. The estimated thermal generation installed capacity is shown in Table 9 below.

	2015	2020	2030
Coal	1756	576	0
CCGT	3829	5595	4605

Table 9: Estimated thermal installed capacity (MW) in Spanish market
Source: DGDEG

Technical data used in the model includes total installed capacity, maximum and minimum output per unit, availability factor, efficiencies and CO_2 emission factors shown in Table 10 below.

	Area Name	Total Installed Capacity [MW]	Number [number]	Maximum output [MW]	Minimum output [MW]	Availability Factor [p.u.]	Efficiencies [p.u.]	CO$_2$ Emission factor [p.u.]
NC1	Spain	1056	3	352	88	0.85	80%	1
NC2	Spain	2191	7	313	78.25	0.85	80%	1
NC3	Spain	689.27	2	344.64	86.16	0.85	80%	1
NC4	Spain	596.2	2	298.1	74.53	0.85	80%	1
IC1	Spain	851	5	170.2	42.55	0.85	80%	0.9
IC2	Spain	4843	13	372.54	93.13	0.85	80%	0.9
CCGT1	Spain	8178.11	17	481.07	192.43	0.9	85%	0.36
CCGT2	Spain	9255.37	19	487.12	194.85	0.9	85%	0.36
CCGT3	Spain	1605.33	3	535.11	214.04	0.9	85%	0.36
Nuclear	Spain	7572.58	8	946.57	889.78	0.94	100%	n.a.

Table 10: Technical data of thermal units in 2015
Source: Own elaboration

3.3.2.2 Hydroelectric stations

Hydroelectric station is another important component in the market; 23.8% of the busbar demand in 2014 was fulfilled by hydroelectric stations (REE, 2015). Hydroelectric station could generate electricity with more flexibility to connect, disconnect and modify the output. And it generates less pollution than thermal units.

Hydroelectric stations could be grouped under two main categories, big hydro stations and pumping power stations, distinguished by system operation. An aggregated model has been used to represent both categories. Pumping power station group includes pure pumping storage units and mixed pumping storage units depending on whether there are nature inflows, in addition to pumped ones, coming into reservoirs.

In the Spanish system, big hydro capacity is expected to remain almost constant from 2015 up to 2020 while additional 400MW of pure pumping storage capacity is expected to enter in the system from 2016, according to CNMC predictions. No new investment on hydroelectric stations under ordinary regime from 2020 to 2030 has been assumed. Table 11 shows the estimated installed capacity of hydroelectric stations in Spain.

Mixed pumping storage capacity has been split under the assumption that part of this capacity behaves as large hydro and part as pure pumping storage; real historical data has been used to set this proportion and detail on the approach taken for this calculation is included in Annex 1.

	2015	2020	2030
Big hydro units	12.7	12.7	12.7
Pure pumping storage units	3.4	3.8	3.8
Mixed pumping Storage units	2.6	2.6	2.6

Table 11: Estimated Installed capacity of hydroelectric stations in Spain (TW)
Source: CNMC, REE

As mentioned in the description of the model, large hydro production has been modeled distinguishing between dispatchable and not dispatchable production (run-of-river). Run of river production is assumed constant each month, calculated based on historical data[15] and proportionally adjusted with increases on capacity envisaged. Figure 2 shows equivalent big hydro units production and run-of-river production[16]. Dispatchable production of large hydro is then calculated subtracting the estimated monthly production of run-of-river units from assumed monthly production of big hydro. Table 12 shows resulting dispatchable and non-dispatchable production of large hydro used as input.

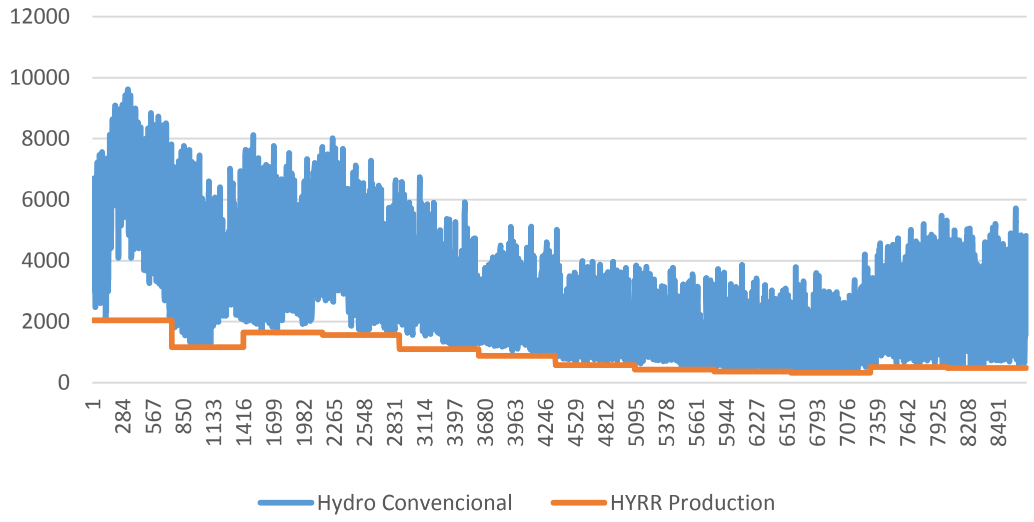

Figure 2: Big hydro and run-of-river producing profile in 2011 in Spanish market
Source: Own elaboration

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[15] Hydro production profile of 2011 has been chosen as a reference because rainfall in this year was close to average.

[16]The data is from energy program: P48 annual energy balance, http://www.esios.ree.es/web-publica/

	"BigHydro"+ROR Pro	"BigHydro"	ROR pro
2011 Ref	25.13	17.05	8.07
2015	25.55	17.34	8.21
2020	25.60	17.37	8.23
2030	25.60	17.37	8.23

Table 12: Annual production of hydroelectric stations in Spanish market (TWh)
Source: CNMC

In the Portuguese case, new hydroelectricity capacity is predicted to enter the system in the center scenario from DGDEG. From 2015 to 2020, 542 MW of new big hydro capacity and 880 MW of pumping storage are expected to come into operation. From 2020 to 2030, three pumping storage units with total installed capacity of 1100 MW will start to function. Same assumptions as in the Spanish case for calculating dispatchable and non-dispatchable production have been considered. Table 13 and 14 below give the Installed capacity and annual production of hydroelectric stations in Portuguese market as inputs in the model.

	Big hydro +run of river	pumping
2015	3990	1527
2020	4532	4016
2030	5074	4532

Table 13: Installed capacity (MW) evolution of hydroelectric stations in Portuguese market
Source: DGDEM

	"BigHydro"+ROR Pro	"BigHydro"	ROR pro
2015	13.00	8.97	4.03
2020	14.77	10.19	4.58
2030	16.53	11.41	5.12

Table 14: Annual production of hydroelectric stations in Portuguese market (TWh)
Source: DGDEM, Own elaboration

3.3.2.3 Technologies under regulated retribution schemes

In Spanish market, technologies under regulated retribution schemes include small hydro (under 50MW), wind, PV solar, CSP, biomass and biogas, waste and cogeneration. Production of these technologies is remunerated under the regulated scheme set by

Royal Decree 413/2014. In this model offers of facilities under special regime are assumed to be 0 Euros/MWh to make sure they will enter the market.

Wind, PV solar and CSP hourly production is determined using historical profiles (see an example in Figure 3), for the rest of technologies under special regime a flat profile has been used.

In line with the prediction from DGDEM on the installed capacity in electricity sector in 2020, wind and hydroelectric energy will keep its dominant position in the renewable share, the installed capacity of wind generation and solar PV generation will increase 17 % and 21% comparing with 2015 level.

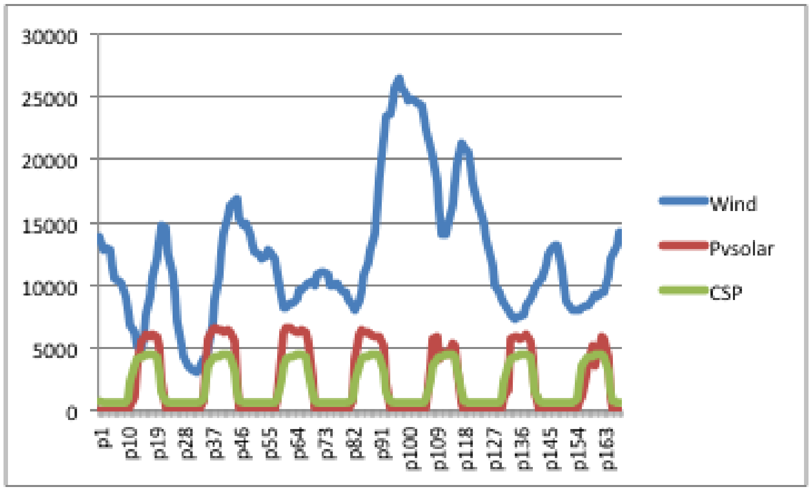
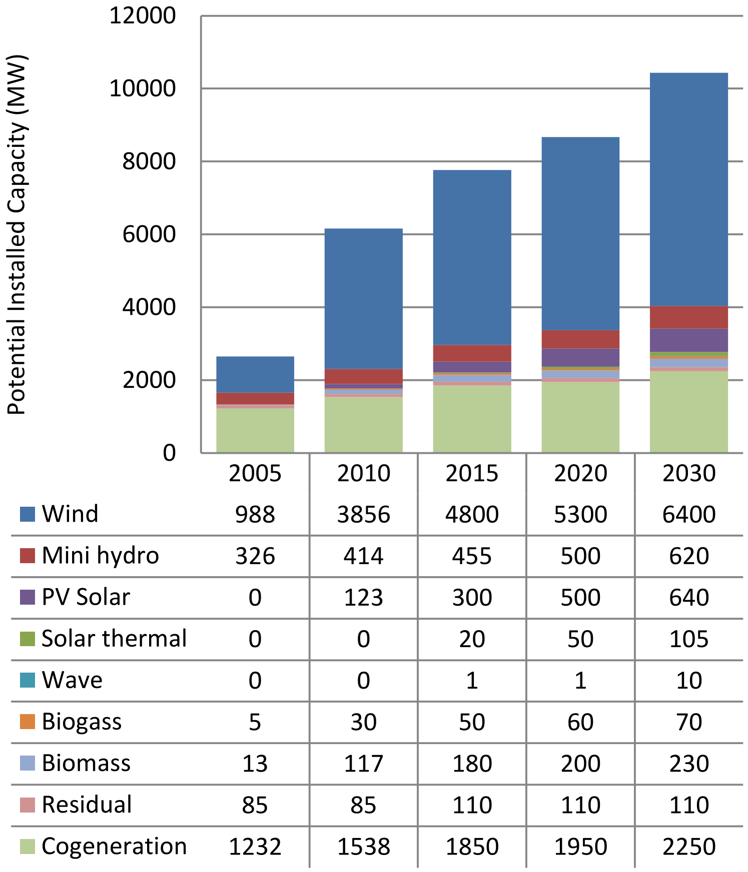


Figure 3: the production profile in a week of September in 2015
Source: Own elaboration

In order to share the renewable share target in 2030 by each type of renewable technology in electricity sector, different ways to promote renewable energy development are applied which lead to different scenarios for the coming analysis. See Chapter 4.4 to find related scenarios of different renewable penetration planning.

In the Portuguese case, the evolution of installed capacity under special regime is assumed to equal predicted capacity in the base scenario of Monitoring report of security of supply of the National Electricity System 2013-2030, issued by DGDEG in 2013. Wind generation is expected to take a leading role under the special regime in Portugal as well. Except energy from waste, all others technologies are expected to increase their capacity gradually from year 2015 to 2030 without varying significantly their share. See the evolution of installed capacity under special regime in Portugal in

Figure 4. Moreover, similar generation profile with Spanish market case of these technologies under special regime is applied.



	2005	2010	2015	2020	2030
Wind	988	3856	4800	5300	6400
Mini hydro	326	414	455	500	620
PV Solar	0	123	300	500	640
Solar thermal	0	0	20	50	105
Wave	0	0	1	1	10
Biogass	5	30	50	60	70
Biomass	13	117	180	200	230
Residual	85	85	110	110	110
Cogeneration	1232	1538	1850	1950	2250

Figure 4: the evolution of installed capacity under special regime in Portugal
Source: DGDEG

3.3.3 Electricity generation costs

From the generation data from REE (2015), it is clear that coal and gas are the only fossil fuel used to generate electricity in Spanish market. In particular, even accompanying with the rapid development of renewable energy, thermal technologies under ordinary regime represent 36% of total installed capacity and 25% of electricity production. Nuclear keeps a quite steady share that represents 8% of total installed capacity while contributes 21% of electricity production in 2014.

This section presents hypothesis and data used to estimate generation costs of thermal units and nuclear. In the case of thermal units, variable costs and fixed term costs have been calculated with data presented in this section though the use of simplified linearized input-output curves (see Annex 2).

3.3.3.1 *Thermal units generation costs:* fossil fuel price

Fuel costs of national coal units have been calculated based on historical recognized fuel cost under Security of Supply Mechanism and increased partially with inflation and partially with the evolution of international coal prices.

Future gas and international coal prices have been taken from WEO price predictions under the New Energy policies Scenario[17].

In the case of CCGT, it is assumed that in 2020 a liquid trading hub in Spain would make fuel costs converge among units, removing potential differences in the past due to the lack of a reference price. Thermal units in Spain and Portugal are assumed to have access to similar coal and gas prices in the future.

In 2015, three different levels of gas prices have been assumed representing access of the units to different price levels under bilateral contracts assumed at 100% of hub-traded prices, 80% of hub-traded prices and 65% of hub-traded prices. Units have been group under each of these three groups according to their past full load working hours that are assumed to reflect fuel cost competitiveness. Portuguese gas plants are assumed to share similar costs to middle-range units in the model. See the fuel import prices in table below.

EU fuel import prices	2015	2020	2030
Gas (in € per MWh)	22.29	27.03	47.45
International Coal (in € per MWh)	9.21	17.22	21.9

Table 15: fuel import prices
Source: CNMC, PROMETHEUS

3.3.3.2 *Thermal units generation costs:* carbon prices

Carbon price not only effects on energy market share, but also incentivizes the investment on clean and low-carbon technologies when set properly. In the model, carbon price in 2015 is set according to CNMC report; carbon price in 2020 is from the estimation of Thomson Reuters Point Carbon (TRPC, 2012); carbon price in 2030 is from the Impacts assessment of EU (see section 4.1 for explanation with more details).

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[17] Which considers that announced environmental policies are implemented.

3.3.3.3 *Thermal units generation costs*: O&M costs

O&M costs are generally regarded to depend linearly on the gross output (see the linearization of input-output curve explained in Appendix A.2 and value used for O&M cost in table 16).

	Fuel cost [€/MWh]	CO_2 cost [€/MWh]	o&m cost [€/MWh]	taxes [€/MWh]	VariableCost [€/MWh]	StartupCost [€/startup]	FixTermCost [€/h]
NC1	26.86	6.23	2.5	10.55	46.14	39600	1822
NC2	29.91	6.21	2	10.73	48.85	35213	1810
NC3	32.25	6.19	2	10.89	51.34	38771	2154
NC4	39.13	6.16	2	11.37	58.66	33536	2271
IC1	17.41	5.67	1.5	13.03	37.61	19148	565
IC2	15.84	5.69	1.5	12.92	35.95	41911	1121
CCGT1	28.02	2.31	2.4	8.98	41.71	25256	1779
CCGT2	34.43	2.31	2.4	9.43	48.56	25574	2217
CCGT3	42.96	2.3	2.4	10.02	57.69	28093	3045
Nuclear	6.3	0	7.1	1.56	14.96		

Table 16: Costs of thermal groups in 2015

Source: Own elaboration

3.3.3.4 *Thermal units generation costs*: Start-up costs

The model has been simplified without differentiating between cold and warm start-ups of thermal units. For calculating total start-up cost an average unitary cost between warm and cold start-up cost has been used. Table 16 gives the start-up costs of each group of units used in this model.

3.3.3.5 *Nuclear generation costs*

Fuel costs of nuclear energy are quiet lower that fossil fuel costs deriving in lower variable costs. Variable costs of this technology have been calculated adding up estimated fossil fuel costs, O&M costs and production tax, shown in table 16.

3.3.3.6 Taxes and tolls applying to thermal power generators in Spain and Portugal

Taxes and tolls included in variable costs of Spanish thermal units are: production tolls[18], Green Penny[19] and 7% production tax[20].

In Spanish market, production tolls is one of the measures to correct tariff deficit in electricity sector. Producers need to pay the production tolls in order to assess the

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[18] Introduced by Royal Decree Law 14/2010 23 of diciembre, and set at 0,5€/MWh

[19] Applying to fossil fuel consumption for power generation after the publication of Law 15/2012 and set at 0,65€/GJ

[20] Law 15/2012

transmission and distribution grids. Green penny is a tax measure to maintain the energy sustainability.

In Portuguese case, apart from production tax, a regulatory mechanism[21] aimed to correct possible imbalances in the wholesale market caused by 'non-market' factors affecting Portuguese power producers has been considered. Portuguese generators in Ordinary Regime would have to pay Third Party Access Tariffs as a way to compensate these distortions[22].

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[21] Established in Decree Law n.º74/2013

[22] The Decree Law also makes The Regulator (ERSE) responsible for elaborating each six months a study evaluating the existence of distortions in the market.

4 Case study – Scenarios' description

4.1 Introduction

This chapter describes the case study developed in this thesis in order to both test the model explained in the previous chapter, and show some of their potential uses when assessing European energy policies.

These variables will be affected by European policies to be implemented in order to deliver the 2030 targets:

- CO2 price
- Renewable energy market share in the Iberian electricity market

These variables will be affected by European policies to be implemented in order to meet the 2030 targets. For instance:

- CO_2 price will be affected by the specific policies and regulation on the European Emissions' Trading Scheme (ETS). Different policies and regulations are being analyzed in this regard such the so-called 'back-loading' or the market stability reserve.
- Renewable energy market share in the Iberian electricity market will be affected by the mechanism to be implemented in order to 'distribute' the renewable energy European target among the different Member States, and the corresponding national policies/regulation which will 'distribute' the hypothetical national target among the different energy sectors (i.e.: transport, heating, electricity). In addition, the way to promote renewable energy development (i.e.: wind and PV solar focus, diversified promotion) will also effect on the renewable energy share.

Thus, the case study could contribute with a modest input to the debate on the most appropriate alternatives when designing these policies.

Notwithstanding, the objective is not to make policy recommendations at this stage, but just to show preliminary results on potential effects that should be further tested through further research and modelling sophistication.

4.2 Scenarios: general description

4.2.1 CO_2 price

Two scenarios have been considered:

- High price: 40 €/tonCO_2 in 2030
- Low price: 22 €/tonCO_2 in 2030

The rationale for each of these two scenarios is explained in section 4.3 and Annex 3.

4.2.2 Renewable energy market share in the Iberian electricity market

These scenarios are built following three steps:

- First, a national renewable energy target for Spain and Portugal is chosen.
- Second, the national target is distributed among the different energy sectors in order to obtain a specific target for the electricity sector.
- Third, the target for the electricity sector is distributed among different renewable electricity generation technologies.

For simplification, the scenarios have been organized as follows:

- A Reference Scenario has been considered with the following characteristics:

Scenario	Spanish national RES target	Spanish power sector RES target	Spanish power sector RES target – Technology distribution	Portuguese national RES target	Portuguese power sector RES target – Technology distribution
Reference	27%	47.8%	Wind & PV focus	37%	Diversified

- The Reference Scenario is compared first with two alternative scenarios which consider a higher and a lower RES target for the power sector :

Scenario	Spanish national RES target	Spanish power sector RES target	Spanish power sector RES target – Technology distribution	Portuguese national RES target	Portuguese power sector RES target – Technology distribution
HT	30%	53.1%	Wind & PV focus	35%	Diversified
LT	27%	40.3%	Wind & PV focus	37%	Diversified

- Finally, the Reference Scenario is compared with an alternative scenario which applies the same RES target for the power sector, but distributing it among the different potential technologies in a diversified manner instead of just focusing on wind and PV solar:

Scenario	Spanish national RES target	Spanish power sector RES target	Spanish power sector RES target – Technology distribution	Portuguese national RES target	Portuguese power sector RES target – Technology distribution
QT	27%	47.8%	Diversified	37%	Diversified

The rationale for these different scenarios is explained in section 4.4.

4.3 CO_2 price – scenarios: rationale

In this study the carbon price for 2020 has been derived from the estimation from Thomson Reuters Point Carbon (TRPC, 2012) taking into considering the "back-loading" scenario[23], which is the only mechanism applied during this time period that will drive the carbon price changing and has been approved by the Parliament and Council with an amendment to the ETS Directive in December 2013 (EC, 2013).

Then the scenarios most similar to 2030 targets from Impacts Assessments of "a policy framework for climate and energy in the period from 2020 to 2030"(EC, 2014d) were chosen to formulate the CO_2 prices for 2030[24].

Table below gives the CO_2 prices used in this study.

		€/ton	Source
2015		11	Current price
2020		8	Thomson Reuters Point Carbon
2030	Option c.1 (High)	40	GHG40
	Option c.2 (Low)	22	GHG40/EE

Table 17: CO_2 price as inputs for the model
Source: Impact assessment

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[23] See Annex 3 for more explanation on ETS and "back-loading" mechanism.

[24] See Annex 3 for more details.

4.4 Renewable energy market share in the Iberian electricity market – scenarios: rationale

4.4.1 2030 renewable target overview

During the transition process towards a competitive, secure and sustainable energy system, renewable energy penetration is gaining more and more attention. The Commission has proposed an objective of increasing the share of renewable energy to at least 27% of the EU's energy consumption by 2030, which was approved by European Council with target binding at the EU level.

One of the most obvious differences between 2020 package and 2030 framework is that the binding national targets are not going to be bond from 2030. Instead of it, the EC has only set an EU level target and will introduce a guiding mechanism to help Member States to set their own target.

In this study, we have proposed to use two different methodologies to set the national level renewable targets to contribute on the EU level target.

Option n.1 is to adapt the same methodology of assigning national targets for 2020 objectives in Directive 2009/28/EC that is on the basis of a formula that applies a flat rate increase in the share of renewable energy with taking into account GDP (EU, 2008).

Option n.2 is to share the renewable target based on the analysis of national resource potentials and the effort from Member States made in the past to achieve 2020 target, which was also been proposed when setting up the sharing methodology for 2020 target in Directive 2009/28/EC.

4.4.2 National renewable target based on a flat increase rate and GDP

The methodology of sharing the EU level target among each Member State based on a flat increase rate and GDP applied for sharing 2020 target is described with more details here:

- Firstly, the gross final energy consumption in 2020 is needed to know. It is estimated by PRIMES model with "cost-efficient" reference case. 20% of this figure is the total amount of renewable energy production in 2020 to achieve 20% renewable target.

- Then the share of renewable energy in 2005 (start point) is adjusted to reflect effort already made on renewable penetration by a reduction of a third of the growth of renewable share in 2005 on those Member States with renewable energy growth more than 2% over 2001 and 2005 (EU, 2008).

- By subtracting of 2005 adjusted renewable energy production from 2020 renewable target, the required additional effort is determined.

- The additional effort to achieve the target is fulfilled from two parts. One part is from requiring a fixed percentage increase apportioned to all Member States and the other part is from allocating the renewable energy share increase according to the economic strength of each Member State measured by DGP per capita.

Applying the same allocation logic of 2020 target among Member States, A. Held, Ma. Ragwitz and etc. (2014) have estimated the national 2030 targets for Member States. According to their study, Spain is going to set a national target at 27% renewable share of final gross energy consumption with the EU level target at 27%,. For Portugal the 2030 national renewable energy share target is estimated to be 37% accordingly.

4.4.3 National targets based on renewable potential estimation

In Directive 2009/28/EC, it also mentioned another option for assigning 2020 national renewable targets that is to share the renewable target among Member States based on renewable potential. The main reason is that potential renewable energy is not distributed equally among all the Member States even though the renewable sources in Europe is quite abundant; for example, the country with plenty of forest resource has a lower marginal cost of renewable energy produced from biomass, so it could be more efficient that the country with higher renewable potentials develop more renewables.

The main source of renewable potential analysis of each Member State country used in this study is from European research project RE-Shaping. RE-Shaping project aims to shape EU renewable energy policies in long term and to help Member States to implement of Directive 2009/28/EC (Ric Hoefnagels, 2011).

The research of this project is based on a comprehensive database with current relative policies, deployment and costs of renewable energies in EU Member States. The existing policies have been evaluated and recommendations are provided to assist further renewable energy source development.

Figure 5 gives the classification of the realizable potential categories which are used though the RE-Shaping project. They are theoretical potential, technical potential, realizable potential and etc.

Theoretical potential is a theoretical value based on current scientific knowledge, which is always the maximum production of one specific resource and theoretical potential is obtained by considering general physical constraint. Technical potential is the potential under consideration of technical conditions (i.e. system performance constraint and land-use constraint). For a certain number of resources, their technical potentials should be considered with a dynamic context (e.g. the technical potential may increase while R&D expenditures increase); Realizable potential is derived assuming under the conditions of all driving forces are functioning well and all existing barriers can be overcome. It also need to be considered under a dynamic context, for example, it need to point out the potential refers to which specific year (Ric Hoefnagels, 2011).

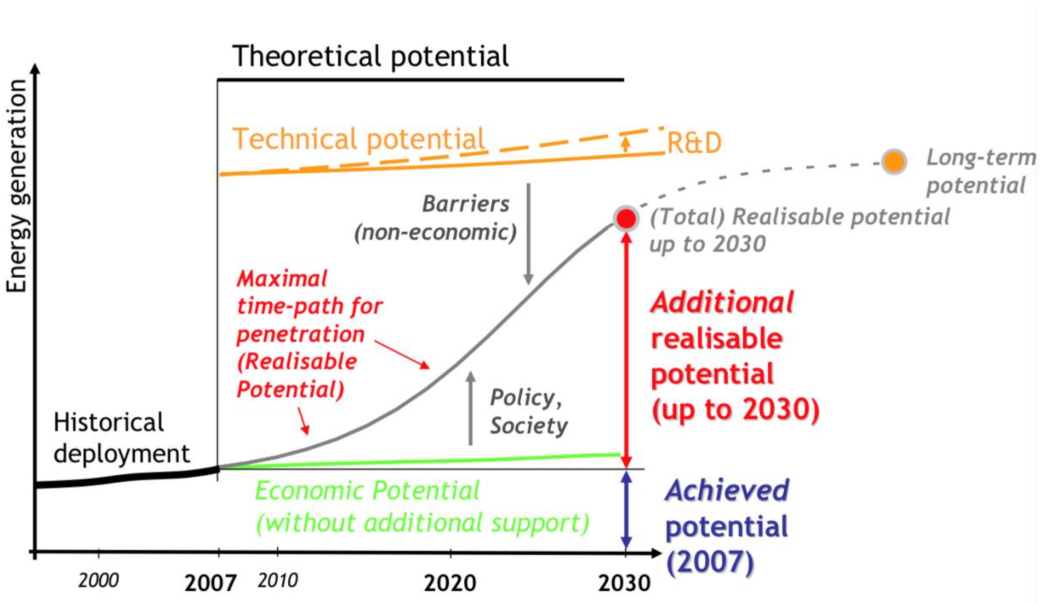

Figure 5: the description of different types of potential
Source: REShaping projects

In the RE-shaping project, dynamic cost-resource curves[25] are applied to analyze the potential renewable energy supply. Costs, potential for electricity generation and demand could vary over years in this method. The model calculates the variations internally. Technologies are included in the potential assessment are: onshore wind, offshore wind, PV solar, concentrated solar thermal, and bioenergy.

The methodology of potential assessment of onshore wind and PV solar will be briefly described in the following part.

For onshore wind potential assessment, instead of existing report taking a perspective from the whole Europe or studying on Member States level without taking into consideration of velocities of local wind or availabilities of land, the RE-Shaping project has developed onshore wind energy potential assessment with derivation of regional cost-resource curves up to 2050.

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[25] See their report for more details. (Ric Hoefnagels, 2011)

The cost-resource curves of onshore wind are derived from the projection of the onshore wind energy potential and the related costs. Moreover, the related costs are derived from in particular investment cost and local wind regimes. Two main factors effecting on onshore wind potential are: local wind regimes influence energy yield of wind turbines and total available onshore wind capacity is determined by the land availability to construct wind turbines.

For solar PV technology, according to the study from Hoogwijk (2004), the total theoretical potential of PV solar energy in Europe is abundant, e.g. in Western Europe solar irradiance reaching Earth as high as 14,400 EJ /year. However comparing the gross final energy consumption PV solar with the theoretical potential, the ratio is very small, it is only 0.33% in 2007 (Ric Hoefnagels, 2011).

There are three main factors to impact on the PV solar energy potential: conversion efficiency, areas available to install equipment and solar irradiation the module (Ric Hoefnagels, 2011). Similar with the derivation of cost-resource curve of onshore wind, the cost-resource curve of PV solar mainly has three parts: economic characteristics of PV solar plants, feasible annual full-load hours from solar irradiation and performance ratio and realizable area potential.

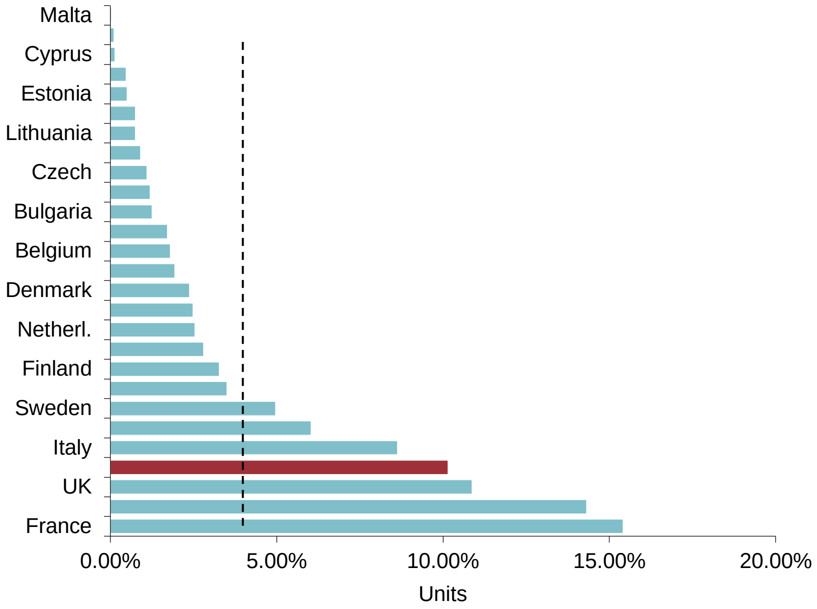

Figure 6: Total relizable renewable potential of EU Member States in 2030

Source: Own elaboration based on RE-Shaping

After accumulating the potential of different sectors of EU 27 countries from Re-Shaping project, the total renewable energy potential of all the Member States have been compared. This total realizable potential in 2030 could be used as a new index to share the renewable energy target based on that those Member States contain more renewable potential should contribute more on the renewable share target. And the effort each country has made in the past could be used as another index in accordance with the assumption that if one country didn´t put enough effort comparing with the average radio (Achieved effort/Total effort instead of the absolute number), this country should work harder from 2020. Figure 6 gives the summary of EU 27 countries total realizable renewable energy potential in 2030 and figure 7 shows the past effort unit 2020.

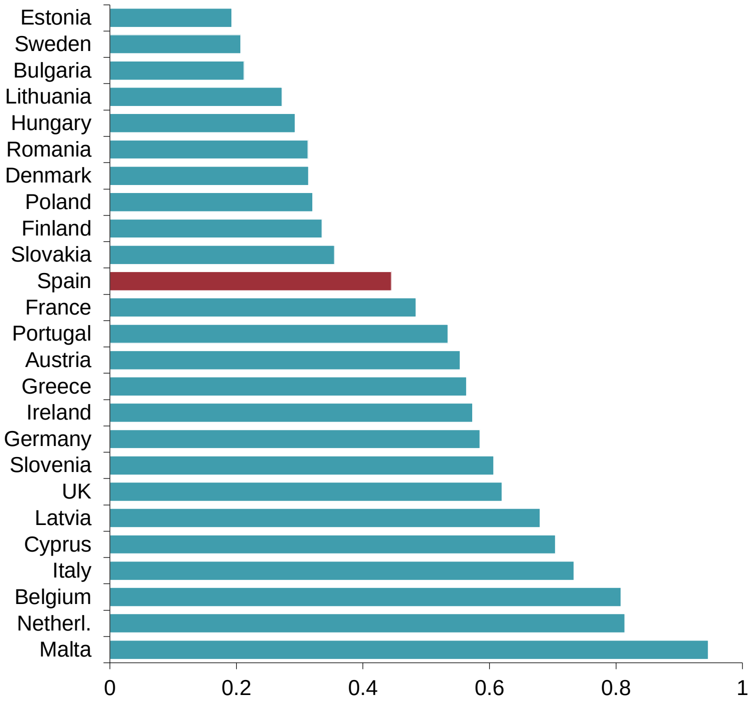

Figure 7: Effort made to achieve 2020 target
Source: Own elaboration based on RE-Shaping

According to the assessment of renewable energy potential and past effort of each Member State, the national renewable share target for Spain is determined to be 30% (slightly higher than the first option) in according to that 10% of the total realizable renewable potential in the EU is from Spain while the average of all the Member States is 3.7%; the past effort from Spain to develop renewable energy is 44% which is slightly lower than the EU average level. On the contrary, Portugal has less total realizable potential in 2030 while it has made more effort in the past, the 2030 national renewable target for Portugal is adjusted to 35% (2% lower) when using option n.2.

To summarize, options for setting national renewable share target for Spain for 2030 are:

Option n.1: 27%, based on a flat increase rate and GDP;

Option n.2: 30%, based on total realizable renewable potential and past effort.

4.4.4 Contribution from electricity sector

After the national level target has been decided, we then need to consider how to cooperate the three main sectors, heating and cooling sector, electricity sector and transport sector together to deliver the renewable penetration target.

The general situation in Spain is that the deployment of renewable energy mainly relies on the electricity sector for delivering target and the reliance on renewable energy of heating and cooling sector is significantly lower than the EU average. As showing in Figure 7, the target is assigned among three sectors for achieving 2020 target of 20% renewable energy share is: 5.6% from heating and cooling sector, 11.7% from electricity sector and 1.7% from transport sector (DGDEM, 2014). As mentioned in the NREAP as well, the electricity sector is going to be the largest contributor to achieve the 2020 renewable share target. Table 18 shows RES sharing target assigned to three sectors in Spain and in Europe.

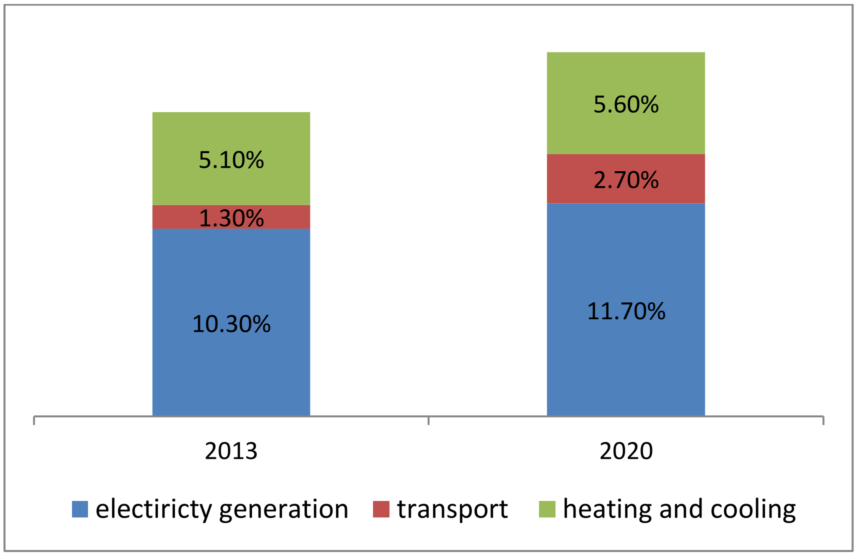

Figure 7: renewable share on final energy consumption in each sector
Source: DMDEG

In this study, two options to set the renewable energy share target for 2030 in electricity sector have been proposed:

Option e.1: to maintain the same ratio of the effort among each sector for 2020 target, which assuming that electricity sector still has enough realizable renewable energy generation potential and the development of renewable penetration will continue.

Option e.2: to shift the contribution ratio towards European average ratio, which assuming that Spanish government will put more effort on heating and cooling sector that contribute less in the past.

Sector	Spain	EU level
Transport	13.50%	12%
Heat/Cooling	28.00%	48.10%
Electricity	58.50%	40.14%

Table 18: RES sharing target assigned to three sectors
Source: European Renewable Energy Council

In this study, the method used to calculate the RES target in electricity sector in 2030 follows the steps below and the numbers are shown in Table 19:

- Firstly the total renewable energy production is derived by multiplying the final gross energy consumption by the 2030 RES national target.

- Then according to different options of adjusting the ratio of the contribution from electricity sector on 2030 RES target and the total renewable energy production calculated in the first step, the renewable energy production from the electricity sector in 2030 in order to achieve the target is derived.

- In accordance with the prediction of annual increasing rate of electricity net demand at 2% from 2020 onwards from CNMC (2015), the net demand of electricity of 2030 is calculated.

- The gross electricity production is derived by assuming that total self-consumption of generators are keep constant assuming that the increasing amount due to increasing of total production could be compensated by the technology improvement.

- At last, electricity target is obtained by dividing the total renewable production by the gross electricity consumption.

	2016	2020	2030	2030	2030	2030
			option n.1 e.1	option n.1 e.2	option n.2 e.1	option n.2 e.2
Total final consumption[26]	85,789	90,788	104,597	104,597	104,597	104,597
Transport		-	-	-	-	-
Heat/Cooling		-	-	-	-	-
Electricity (gross)		29,022	34,563	34,563	34,563	34,563
Electricity (net)		25,300	30,840	30,840	30,840	30,840
RES target		20%	27%	27%	30%	30%
Transport		2.7%	3.4%	3.6%	3.8%	4.1%
Heat/Cooling		5.6%	10.3%	7.6%	11.4%	8.4%
Electricity		11.7%	13.3%	15.8%	14.8%	17.6%
RES production		18,158	28,241	28,241	31,379	31,379
Transport		2,451	3,568	3,813	3,964	4,236
Heat/Cooling		5,084	10,745	7,908	11,939	8,786
Electricity		10,622	13,928	16,521	15,476	18,357
RES target in the electricity sector		36.6%	40.30%	47.80%	44.78%	53.11%

Table 19: Scenarios of RES target in the electricity sector
Source: own elaboration

4.4.5 Renewable target breaking down into different technologies

Spain holds a long history in the development of renewable energy in the energy market. This strategy, started after the energy crisis in 1980, started to harvest at the end of the decade and moreover, it has acquired a certain level of acceleration from 2000 to 2010.

The mandatory minimum target of 20% of renewable energy share in Spain in 2020 is set out in Directive 2009/28/EC. In line with this objective, when setting the plan of renewable energy development, multiple criteria are used to compare with different potential technologies. In this study, the similar multiple criteria consisting by economic criteria, environmental criteria and technical and social criteria, from the renewable energy planning (IDAE, 2011) are used to decide the planning of developing renewable energy among each technology in the electricity sector to meet 2030 target.

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[26] Total final consumption in 2016 and in 2030 is estimated by DGDEG, see (DGDEM, 2014) , we assume the fixed annual increasing rate and apply if after 2020.

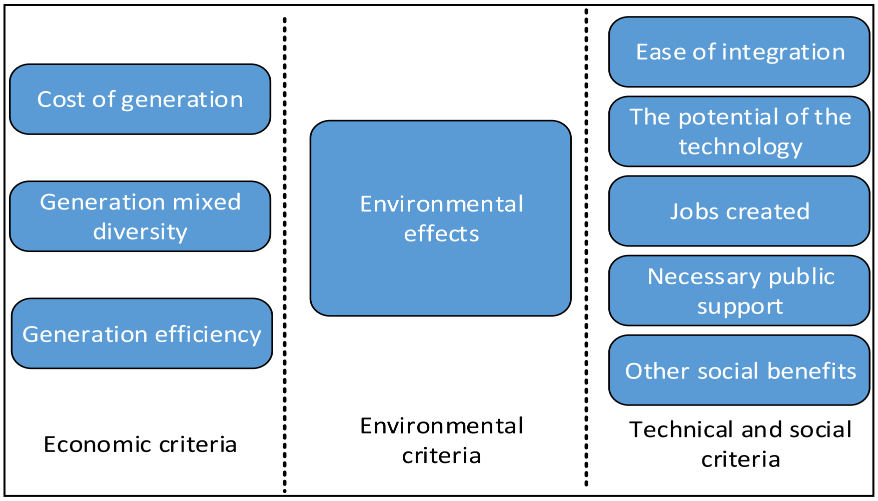

Figure 8: The criteria to assess the investment on different technology
Source: IDEA

Economic criteria has been gaining more attention since the current Spanish economic and world economic situation, for example, currently most of the renewable energy generation units need additional financial compensation in different market to stimulate their development. So impacts from the cost of promotion policies on the market, especially on the electricity market is needed to be considered.

However economic arguments are not the only things need to be considered. The arguments about the development of the industrial sectors and the services related with renewable energy, the relationship between the promotion of renewable energy and the policies promoting the GHG emissions reduction practically offset the economic effects of the promotion of renewable energy.

After the EU level target is set for the share of renewable energy, the multiple criteria analysis will be helpful for assigning different objectives among different potential technologies. The multiple criteria could include many specific components and some possible criteria to assess the distribution of renewable energy development are shown in figure 8.

Another thing worth considering when setting the planning of renewable energy development is the existing potential, which could be considered as another key factor for the decision making. Meanwhile, not all sources of Renewable energy can supply all kinds of purpose, therefore the existing potential is separated by being used for generating electricity or existing potential. The potential of renewable energy could be used for electricity generation or thermal generation. The potential for electricity generation of different technologies in Spain has been shown in Table 20. Solar has the biggest potential and following by Onshore and offshore wind.

Technology	Potential(GW)
Solar	>1000
Onshore + offshore wind	340
Geothermal	19.6
Wave	20
Hydroelectricity	33
Pumping	13
Biomass	8
Waste	1.8
Biogas	1.2

Table 20: Renewable potential in Spain

Source: IDAE

In line with the multiple criteria assessment, DGDEM has made a prediction of installed capacity in electricity sector in 2020. For the renewable energy technologies, wind and hydroelectric energy will keep its dominant position in the renewable share. While big hydro units installed capacity remains the same from 2015, the installed capacity of wind generation and solar PV generation will increase 17 % and 21% comparing with 2015 level.

In order to share the renewable share target by different types of renewable technologies in electricity sector, two options would be applied in this study:

Option t.1: Main emphasis on onshore wind and PV solar source for new renewable energy development planning cost-efficiently (Coherent with the plan trend for 2020);

Option t.2: Fully develop all kinds of renewable technology apportioned to the market share in order to develop the diversity of generation mix.

5 Case study – Results

5.1 Introduction

Next, main results of the simulations run for the different scenarios mentioned in section 4 are presented. In order to facilitate the results' description and conclusions, the chapter has been organized as below:

- Section 5.2 shows a brief summary of main results of the Reference Scenario.
- Section 5.3 compares the main results of the Reference Scenario with those from scenarios HT and LT, in order to assess the effects of a higher and a lower RES target in the power sector.
- Section 5.4 compares the main results of the Reference Scenario with those from scenario QT, in order to evaluate the effects of distributing the RES target of the power sector in a more diversified way among the different potential technologies instead of just focusing on wind and solar PV.

In the three sections, results are shown both for high and low CO_2 prices' scenarios.

Results focus on variables such as: market price, generation cost, fuel import dependence, generation mix, CO_2 emission reduction and interconnection usage rate.

5.2 Reference Scenario

In order to make sure the total installed capacity in the system will be able to cover the demand requirement, the reserved margin of the system should be above 1.1. The reserve margin is 1.104 in Reference Scenario, which is higher than 1.1 so no more extra investments is needed.

5.2.1 Generation cost, cost structure and market price

The related costs for generating electricity introduced in our model include: fuel cost, CO_2 emission cost, O&M cost, start-up cost and taxes. From the result summary shown in table 21, in Reference Scenario, it could be seen that the payment from demand with high CO_2 price is 20.07% higher than that with low CO_2 price. And generation cost is 5.62% higher than that with low CO_2 price. So a higher CO_2 price could lead to a higher generation cost and payment from demand, which means when CO_2 is higher, both generator side and consumer side would pay more.

	Payment from demand	Generation Cost	Weighted Ave.Price
	Billion €	Billion €	€/MWh
High CO_2 Price			
Scenario Reference	39.42	7.52	116.63
Low CO_2 Price			
Scenario Reference	32.83	7.12	97.11

Table 21: result summary of Reference Scenario
Source: Own elaboration

Generation cost of electricity depends on many different things. For example, for some units, the cost mainly depends on the volatility of the international fuel market price since fuel they consume may be very expensive which takes a big part of the total cost. In Reference Scenario, CO_2 cost is only 0.2% lower in the case of high CO_2 price (13.552%) than in the case of low CO_2 price (13.731%). Fuel cost accounts for 75.28% and 73.37% of the total cost which keeps the dominate position in both cases.

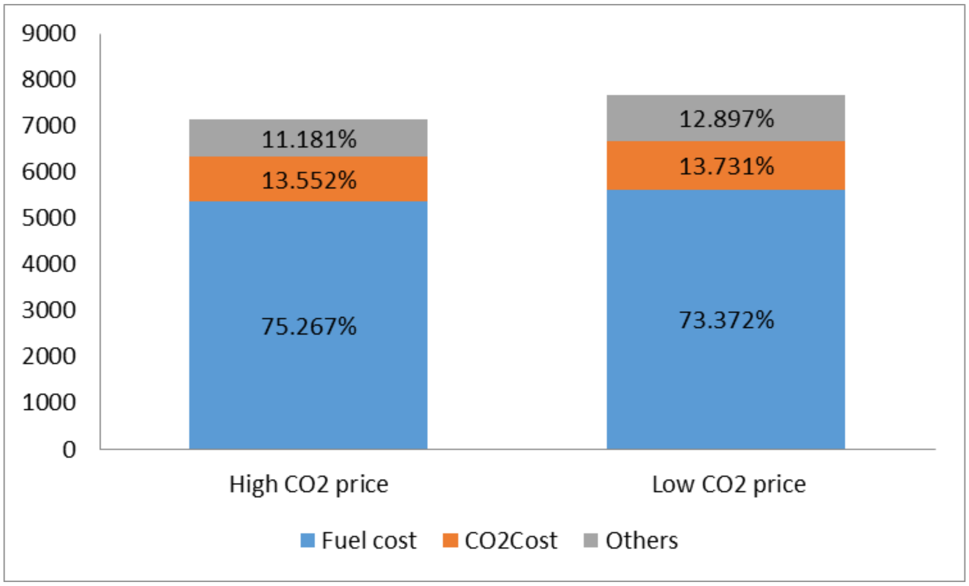

Figure 9 Generation cost structure in Reference Scenarios with different CO_2 price
Source: Own elaboration

The marginal prices are derived from marginal costs[27] under the assumption of perfect competition (Mariano Ventosa, 2013). Based on this, the production weighted average marginal price is calculated from the model output (116.63 euros/MWh with high CO_2 price and 97.11 euros/MWh with low CO_2 price), which could mitigate the inaccuracy due to the production differences at each hour. In line with generation costs, high CO_2 price will bring a high market price.

5.2.2 Interconnection usage

The interconnection usage between the two sub-markets may be different under different extent (ambitious or moderate) to develop renewable energies in the electricity market to meet the EU 2030 target in the future. The congestion rates with different CO_2 prices are very similar (16.19% in Reference Scenario with High CO_2 price and 16.85% with low CO_2 price) so only changing in CO_2 prices will not have big influence on congestion rates in the system.

5.2.3 CO_2 emission

The results from the models show that the CO_2 emission of 2030 is 16.26 million ton with high CO_2 price and 32.24 million ton with low CO_2 price. By increasing the CO_2 price from 22 euros/ MWh to 40 euros/MWh, the CO_2 emission could reduce around 50%.

This justified that except that renewable energy share target, to develop renewable energy penetration could also bring significant effort on reducing GHG emissions, which is another key point in the 2030 framework.

5.2.4 Generation mix and fuel dependence

In low CO_2 price Reference Scenario, Coal plants account for 7.68% of the total production while in high CO_2 price Reference Scenario, they account for only 0.08%. That is to say high CO_2 price may squeeze coal technologies' market share. Moreover, the total production share from thermal generation (coal plants plus CCGT plants) keeps quite stable (13.68% with high CO_2 price and 13.65% with low CO_2 price). High CO_2 prices may shift the fuel dependence from international coal units to CCGT units.

Figure 10 shows the dispatch scheduling in June of 2020 and 2030 (high CO2 price) from the model, it is obvious that with the renewable energy share increasing from 20% to 37%, coal plants and CCGT plants are now working during peak hours in most of the time. But in the past, imported coal plants and CCGT plants were working as base-load plants. The market share structure has been changed.

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[27] Marginal cost is equal to the additional cost of the system when the demand increases by one unit. Both in the centralized context and in the perfect competition market, the optimal solutions are found when the marginal price is equal to the marginal cost.

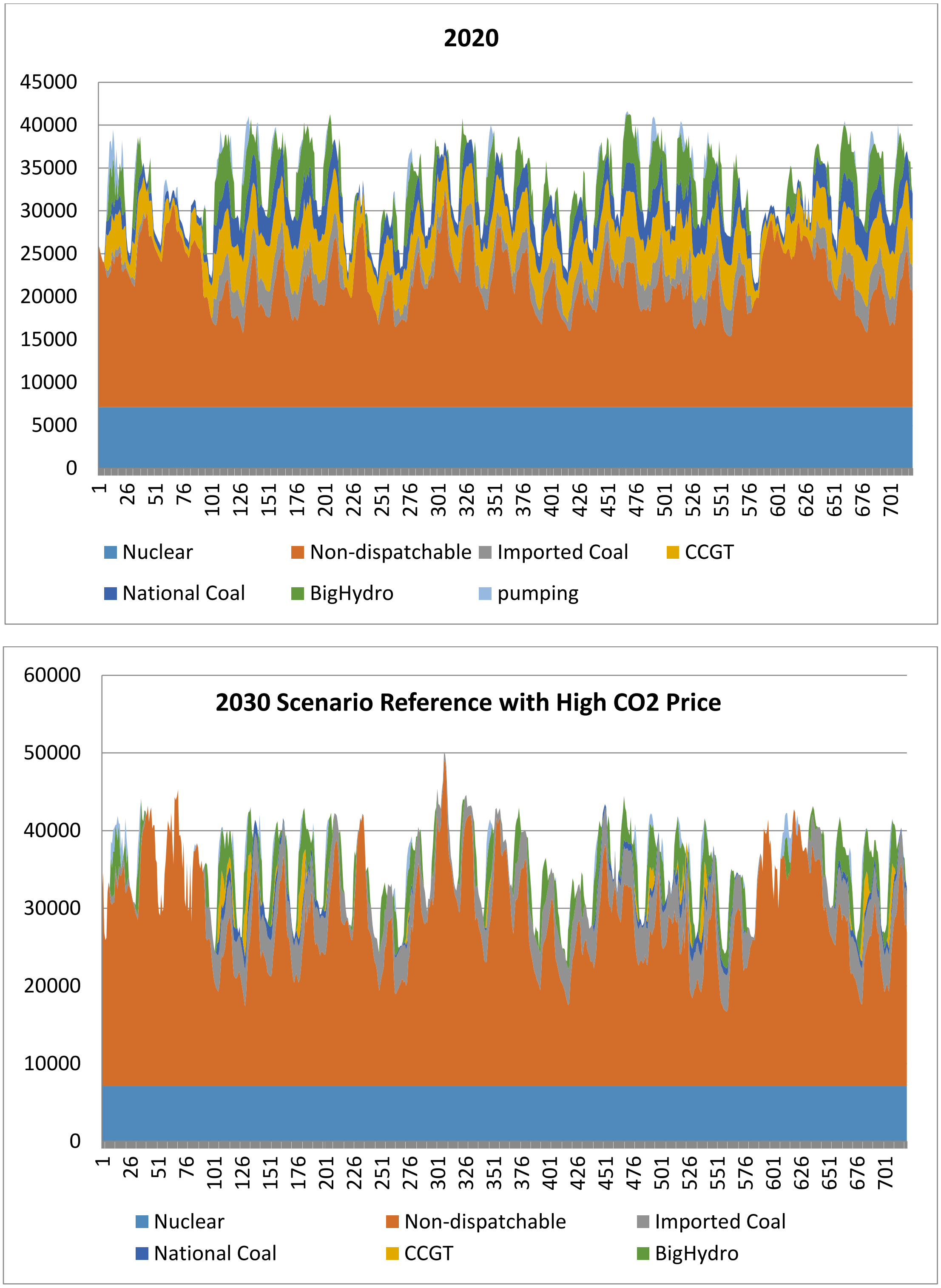

Figure 10: energy dispatch scheduling in May in 2020 and 2030(Scenario Ref. with high CO_2 price)

Source: Own elaboration

5.3 Reference Scenario vs. HT and LT scenarios

In this session the scenarios having different targets which set different renewable energy share in the electricity sector in Spain (namely Scenario Reference, Scenario HT and Scenario LT) have been compared.

Using the combination of different options to set national level targets, electricity sector targets but all applying promoting renewable energy share target only focusing on wind and PV solar technologies, Scenario HT and LT have been made. The reserved margin for Scenario HT is 1.12 so the installed capacity of Scenario HT could guarantee the electricity supply. While for scenario LT, the reserved margin is 1.08.

5.3.1 Investment decision in Scenario LT

In Scenario LT, the expected installed capacity of renewable energy is lower than those of Scenario Reference and Scenario HT because it has a lower target. This leads to that the reserve margin of Scenario LT is 1.08. So additional investment must be introduced into the market to guarantee the energy supply.

Levelized cost of electricity (LCOE) is the price that must be received per unit of output as payment for producing power in order to reach a specified financial return (WEC, 2013). Only with LCOE that power plants of different technologies and cost distribution could be compared with each other. The basic theory of LCOE is to form the sum of costs spent on constructing and running a plant and then to compare the form with the sum of the annual income from the power generation (FRAUNHOFER, 2013). In this study, the investment decision is made mainly considering LCOE.

In Scenario LT, it is assumed a linear increasing tendency of the installed capacity of technologies under special regime in the system from 2020 to 2030 and the mothballed CCGT units reentering into the market once the reserve margin is lower than 1.1. New investment is necessary when all the possible mothballed CCGT units has reentered into the market and the reserve margin is still lower than 1.1.

The first investment is needed before 2029. Since the LCOE of onshore wind (93.14 €/MWh in nominal term) is much lower than that of CCGT[28] both under the conditions of high CO_2 price (175.80 €/MWh) and low CO_2 price (158.12 €/MWh) and the total amount of new installed capacity is lower than one typical CCGT plant, the decision has been made to invest only on onshore wind energy in this Scenario in 2028[29]. When in year 2030, the reserve capacity is below 1.1 again and another investment decision is made following the same way. The Installed capacity of CCGT and wind technology in Spanish market from 2025 to 2030 in Scenario LT is shown in Figure 11.

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[28] See annex A.4 for the cash flow model to calculate the LCOE of the CCGT technologies

[29] It has been assumed that within one year, the construction is completed and the wind farm is ready to produce.

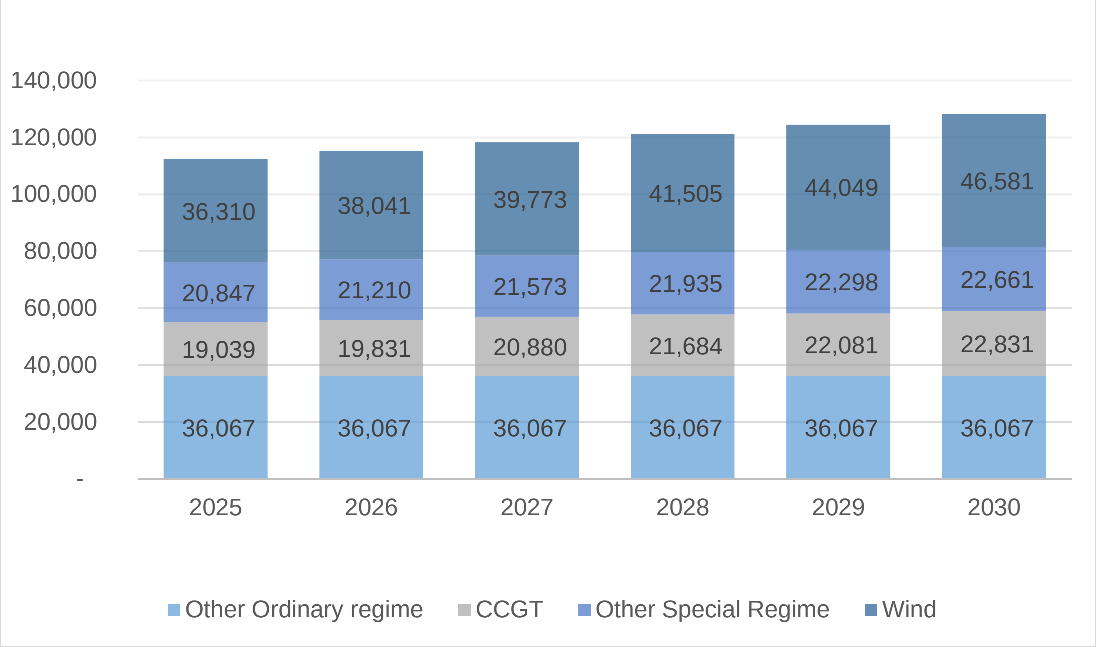


Figure 11: Installed capacity in electricity sector in Spain from 2025 to 2030 in Scenario LT
Source: Own elaboration

	Reference Scenario	HT Scenario	LT Scenario
Conventional Hydro	15.29	15.29	15.29
Pumping Storage	3.77	3.77	3.77
Nuclear	7.57	7.57	7.57
Coal	9.44	9.44	9.44
CCGT	22.08	22.08	22.83
Hydro renewable	2.30	2.30	2.30
Wind	56.68	64.98	46.58
Solar PV	11.87	13.61	9.42
Solar Thermal	2.30	2.30	2.30
Thermal RE	1.25	1.25	1.25
Thermal NRE	7.39	7.39	7.39
Total	139.94	149.97	128.14
Reserve Margin	1.10	1.12	1.10

Table 22: Installed capacity (GW) in the Spanish electricity market in 2030
Source: Own elaboration based on DGDEM projection

Table 22 shows the installed capacity breakdown into ordinary regime (grey part) and special regime (blue part) and into different technologies in 2030 in Reference Scenario, Scenario HT and Scenario LT separately. The differences among different scenarios are due to different electricity targets. For the technologies under special regime, the installed capacity of wind and PV solar are different accordingly in all the three scenarios, while other technologies except wind and PV solar are keep the same installed capacity as in 2020. Under ordinary regime, in scenario LT, according to the investment decisions we have made before, the installed capacity of CCGT units are 750 MW higher than that of the other two scenarios.

5.3.2 Generation cost, cost structure and market price

As shown in table 23, Scenario HT has the lowest payment from demand (31.18 billion euros with high CO_2 price and 28.47 billion euros with low CO_2 price), generation cost (6.24 billion euros with high CO_2 price and 6 billion euros with low CO_2 price), and weighted average price (92.25 euros/MWh high CO_2 price and 84.21 euros/MWh), while Scenario LT is the other way around due to Scenario HT contains more installed capacity of renewable energy with opportunity cost at 0 euros/ MWh while Scenario LT contains less.

Figure 12 shows generation cost structure in each scenario with high CO_2 price and low CO_2 price. No matter with a high CO_2 price or low CO_2 price, the cost structure is quite stable; around three-quarters of total costs are from fuel cost. The left one-quarter are from CO_2 cost, taxes and etc.

	Payment from demand	Generation Cost	Weighted Ave.Price
	Billion €	Billion €	€/MWh
High CO_2 Price			
Scenario Reference	39.42	7.52	116.63
Scenario HT	31.18	6.24	92.25
Scenario LT	43.65	9.72	129.12
Low CO_2 Price			
Scenario Reference	32.83	7.12	97.11
Scenario HT	28.47	6.00	84.21
Scenario LT	38.79	9.09	114.76

Table 23: Result summary of Scenario RE, Scenario HT and Scenario LT
Source: Own elaboration

Figure 12: Generation cost structure in different scenarios with low CO_2 price
Source: Own elaboration

5.4.3 Interconnection usage

Table 24 contains the congestion rage from the model. The result we got from model is that, if the renewable target is higher, the congestion rate becomes higher as well (31.44% in Scenario HT, 7.4% in Scenario LT with high CO_2 price and 28.08% in Scenario HT, 8.61% with low CO_2 price). That means that we may need to break the limitation of energy exchange by investing on the interconnection infrastructure to add more capacity. Then the entire system could be more efficient since it could take use of "cheaper" energy as much as possible. Then the system will have a better dispatch scheduling reflecting on lower total cost than the one applied.

	Congestion Rate		Congestion Rate
	p.u.		p.u.
High CO_2 Price		Low CO_2 Price	
Scenario Reference	16.19%	Scenario Reference	16.85%
Scenario HT	31.44%	Scenario HT	28.08%
Scenario LT	7.40%	Scenario LT	8.61%

Table 24: Congestion rage in Scenario Ref. Scenario HT and Scenario LT
Source: Own elaboration

5.3.4 CO_2 emission

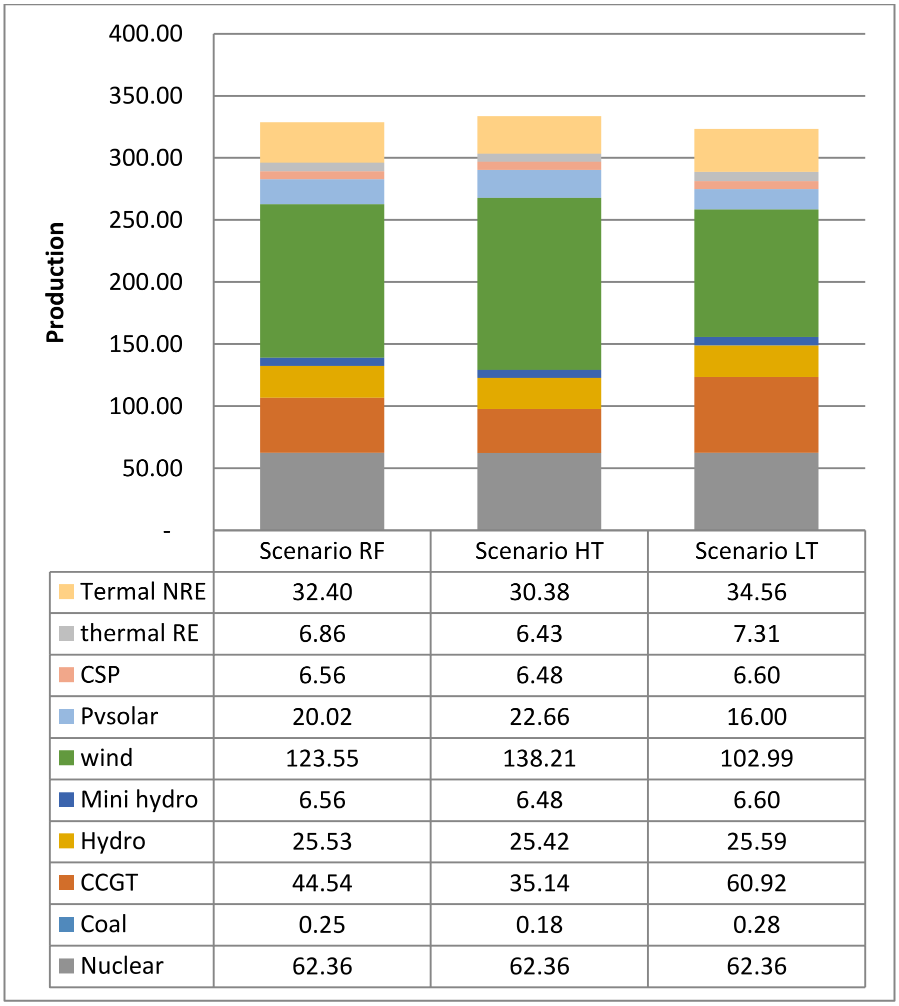
As shown in Table 25, when the renewable energy share level is higher, the emission is lower (CO_2 emission in Scenario HT is higher than that in Scenario LT both with high CO_2 price and low CO_2 price).

	CO_2 emission amount		CO_2 emission amount
	Million Tonne		Million Tonne
High CO_2 Price		Low CO_2 Price	
Scenario Reference	16.26	Scenario Reference	32.24
Scenario Reference	12.81	Scenario Reference	26.58
Scenario Reference	22.19	Scenario Reference	42.40

Table 25: CO_2 emission amount in Scenario Ref. Scenario HT and Scenario LT
Source: Own elaboration

5.3.5 Generation mix and fuel dependence

Figure 13 and 14 show the generation mix in Scenario Reference, Scenario HT and Scenario LT. Nuclear units are keeping the same share in all the scenarios due to the cheapest variable cost and limited flexibility. The share of coal plants and CCGT plants increases when the renewable target is lower. In Scenario Reference and Scenario HT the dominant position of wind generation are more obvious than in Scenario LT, which may need to pay attention because the diversification of the energy also plays a very important role for the supply security. Furthermore, in scenarios with high CO_2 price, the market share of coal generation is almost substituted by CCGT due to the higher variable cost of coal plants. It is justified that right signal of proper CO_2 price would lead to a low carbon economy and it would change the market share structure.

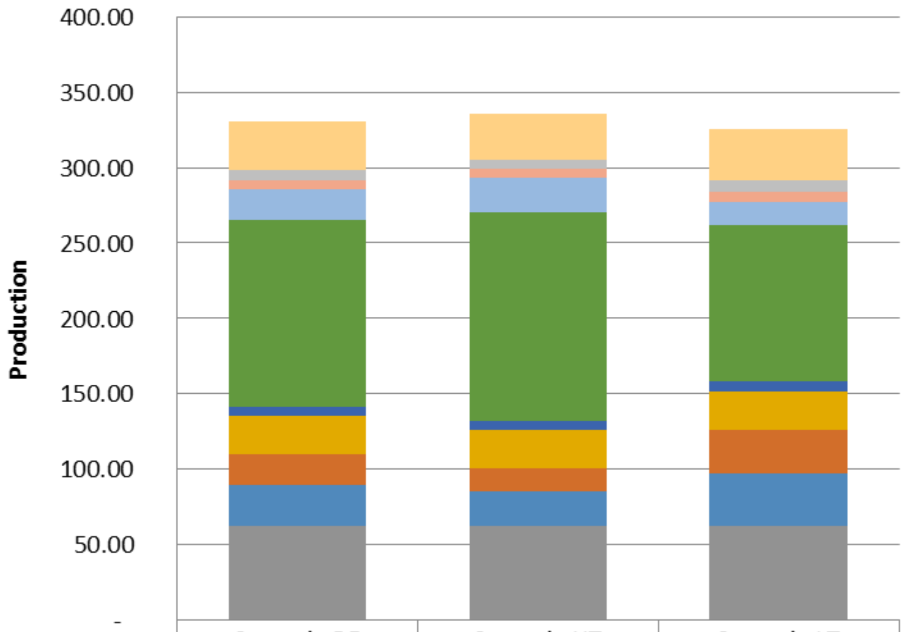


	Scenario RF	Scenario HT	Scenario LT
Termal NRE	32.40	30.38	34.56
thermal RE	6.86	6.43	7.31
CSP	6.56	6.48	6.60
Pvsolar	20.02	22.66	16.00
wind	123.55	138.21	102.99
Mini hydro	6.56	6.48	6.60
Hydro	25.53	25.42	25.59
CCGT	44.54	35.14	60.92
Coal	0.25	0.18	0.28
Nuclear	62.36	62.36	62.36

Figure 13: generation mix in Scenario Ref. Scenario HT and Scenario LT with high CO_2 price

Source: Own elaboration

By comparing the share of the production from imported coal plants and from CCGT pants, impacts on the dependence of imported fuel from renewable penetration could be found. Table 26 shows the market share of imported coal and CCGT plants in each scenario with two options of CO_2 prices. We could find that the promotion of renewable energy could release fuel dependence in certain level. Even though different CO_2 price leads to different ratio of imported coal share and CCGT share, the higher the CO_2 price is set, the lower the import fuel dependence reaches.



	Scenario RF	Scenario HT	Scenario LT
Termal NRE	32.45	30.39	34.51
thermal RE	6.87	6.43	7.30
CPS	6.05	5.67	6.43
Pvsolar	20.01	22.65	16.00
wind	123.49	138.20	103.07
Mini hydro	6.56	6.48	6.61
Hydro	25.53	25.42	25.60
CCGT	19.84	14.64	28.79
Coal	27.50	23.37	35.09
Nuclear	62.36	62.36	62.36

Figure 14: generation mix in Scenario Ref. Scenario HT and Scenario LT with low CO_2 price

Source: Own elaboration

	Scenario RF	Scenario HT	Scenario LT
high CO_2 price			
Imported Coal	0.07%	0.05%	0.08%
CCGT	13.45%	10.45%	18.72%
low CO_2 price			
Imported Coal	7.27%	6.13%	9.38%
CCGT	6.00%	4.36%	8.84%

Table 26: The market share of imported coal plant and CCGT plant
Source: Own elaboration

5.3.6 Summary

Comparing with the Reference Scenario, for higher RES targets in the power sector (HT):

- The generation cost will be 16.98% lower with high CO_2 price and 15.76% lower with low CO_2 price in 2030.
- The market price could be 20.9% lower with high CO_2 price and 13.28% lower with low CO_2 price in 2030.
- The congestion rage of interconnection will increase by 15.25% with high CO_2 price and 11.23% with low CO_2 price.
- The CO_2 emission will be 21.22% lower with high CO_2 price and 17.55% lower with low CO_2 price in 2030.
- Fuel import dependence will be reduced by 3.02% in 2030 with high CO_2 price and 2.78% with low CO_2 price in 2030.

For lower RES targets in the power sector (LT):

- The generation cost will be 29.18% higher with high CO_2 price and 27.63% higher with low CO_2 price in 2030.
- The market price could be 10.71% higher with high CO_2 price and 18.17% higher with low CO_2 price in 2030.
- The congestion rage of interconnection will reduce by 8.79% with high CO_2 price and 8.24% with low CO_2 price.
- The CO_2 emission will be 36.42% higher with high CO_2 price and 31.52% higher with low CO_2 price in 2030.
- Fuel import dependence will be increased by 5.28% with high CO_2 price and 4.94% with low CO_2 price in 2030.

5.4 Analysis on scenarios with different focus to promote renewable energy in the electricity sector

After using the same methodologies to set national renewable target and electricity sector target in Scenario Reference, it has been chosen to use a diversified way to develop renewable energy in Scenario Quota. Impacts brought by the different methodology to promote the renewable energy development among different technologies have been analyzed in this session. Table 27 shows the installed capacity of Scenario Reference and Scenario Quota breakdown into ordinary regime and special regime and into different technologies in 2030. The reserve margin in Scenario Quota reaches 1.12 after the installed capacity of each renewable technology has been expanded according to their market share to reach 2030 target.

	Reference Scenario	Scenario Quota
Conventional Hydro	15.29	15.29
Pumping Storage	3.77	3.77
Nuclear	7.57	7.57
Coal	9.44	9.44
CCGT	22.08	22.08
Hydro renewable	2.30	4.17
Wind	56.68	50.16
Solar PV	11.87	10.50
Solar Thermal	2.30	4.17
Thermal RE	1.25	2.27
Thermal NRE	7.39	7.39
Total	139.94	136.82
Reserve Margin	1.10	1.12

Table 27: Expected Installed capacity of Scenario Reference and Scenario Quota
Source: Own elaboration

After executing Scenario Quota in the model with both high CO_2 price and low CO_2 price, the result has been summarized in Table 28 comparing with Scenario Reference.

5.4.1 Generation cost, cost structure and market price

It could be found that there is no much difference in payment from demand side, generation cost or weighted average price since no matter which type of renewable energy has been development, the opportunity costs of all the renewable energy in the system is 0 euros/MWh and investment costs are not considered in this model.

	Payment from demand	Generation Cost	WA.Price	CO_2 emission amount	Congestion Rate
	Billion €	Billion €	€/MWh	Million Tonne	p.u.
High CO_2 Price					
Scenario Ref.	39.42	7.52	116.63	16.26	16.19%
Scenario QH	39.73	7.15	117.52	15.24	14.52%
Low CO_2 Price					
Scenario Ref.	32.83	7.12	97.11	32.24	16.85%
Scenario QT	34.79	6.87	102.92	31.91	15.14%

Table 28: result summary of Scenario Reference and Scenario Quota
Source: Own elaboration

5.4.2 Interconnection usage

The congestion rate of Scenario Quota (14.52% with high CO_2 price and 15.14% with low CO_2 price) and Scenario Reference (16.19% with high CO_2 price and 16.85% with low CO_2 price) doesn't have much difference. This is because that after the producing decision has been made, they are all the same to supply the demand.

	Congestion Rate		Congestion Rate
	p.u.		p.u.
High CO_2 Price		Low CO_2 Price	
Scenario Reference	16.19%	Scenario Reference	16.85%
Scenario Quota	14.52%	Scenario Quota	15.14%

Table 29: Congestion Rate in Scenario Ref. and Scenario Quota
Source: Own elaboration

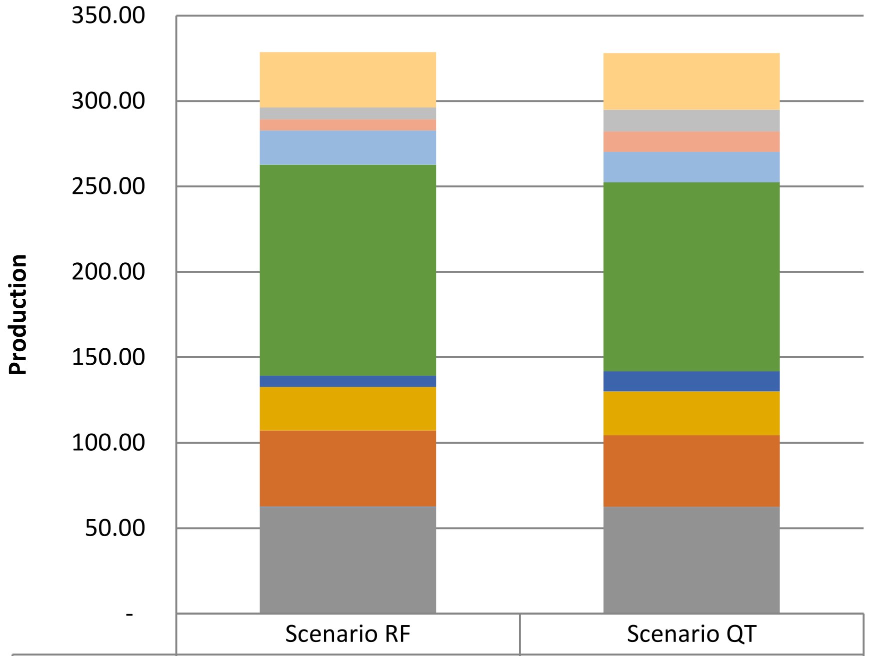
5.4.3 CO_2 emission

	CO_2 emission		CO_2 emission
	Million Tonne		Million Tonne
High CO_2 Price		Low CO_2 Price	
Scenario Reference	16.26	Scenario Reference	32.24
Scenario Quota	15.24	Scenario Quota	31.91

Table 30: CO_2 emission amount
Source: Own elaboration

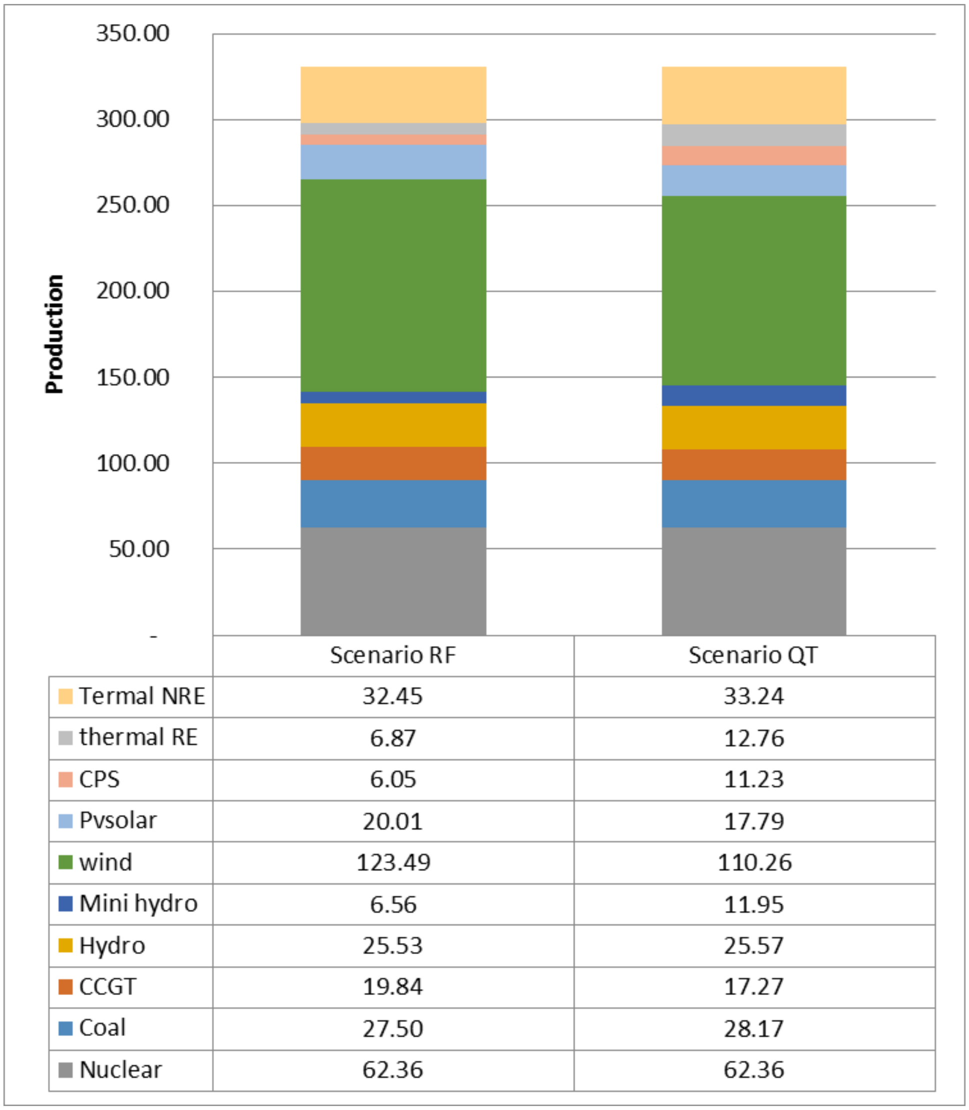
CO_2 emission doesn’t change much between QT Scenario and Reference Scenario (see numbers in table 33) because renewable energy is all clean energy and it could reduce the CO_2 emission.

5.4.4 Generation mix and fuel dependence



	Scenario RF	Scenario QT
■ Termal NRE	32.40	33.14
■ thermal RE	6.86	12.72
■ CSP	6.56	11.96
■ Pvsolar	20.02	17.80
■ wind	123.55	110.41
■ Mini hydro	6.56	11.96
■ Hydro	25.53	25.58
■ CCGT	44.54	41.87
■ Coal	0.25	0.18
■ Nuclear	62.36	62.36

Figure 15: generation mix in Scenario Ref. and Scenario Quota with high CO_2 price
Source: Own elaboration



	Scenario RF	Scenario QT
Termal NRE	32.45	33.24
thermal RE	6.87	12.76
CPS	6.05	11.23
Pvsolar	20.01	17.79
wind	123.49	110.26
Mini hydro	6.56	11.95
Hydro	25.53	25.57
CCGT	19.84	17.27
Coal	27.50	28.17
Nuclear	62.36	62.36

Figure 16: generation mix in Scenario Ref. and Scenario Quota with high CO_2 price
Source: Own elaboration

Figure 15 and Figure 16 show the generation mix in Scenario Reference and Scenario Quota. Similarly to the situation in the previous analysis, nuclear units are keeping the same share in Scenario Quota as well. The share of coal plants and CCGT plants increases when the renewable target is lower. When taking a high CO_2 price, the market share of coal generation is almost substituted by CCGT due to the higher variable cost of coal plants. The market share of wind generation is a little bit lower in Scenario Quota than in Scenario Reference, however its dominate position is still very obvious. The total energy generation under special regime in these two scenarios is slightly different, which is due to the different generation patterns of different technologies.

As it shows in Figure 17 and 18, the cost structure in Scenario Quota is also similar to the ones of the previous scenarios. Most of the cost (three-quarters) is due to fuel cost. CO_2 cost is almost 15%. Even though the CO_2 cost share doesn't change much when CO_2 price is lower, the total CO_2 emission increased. See the numbers in table 30.

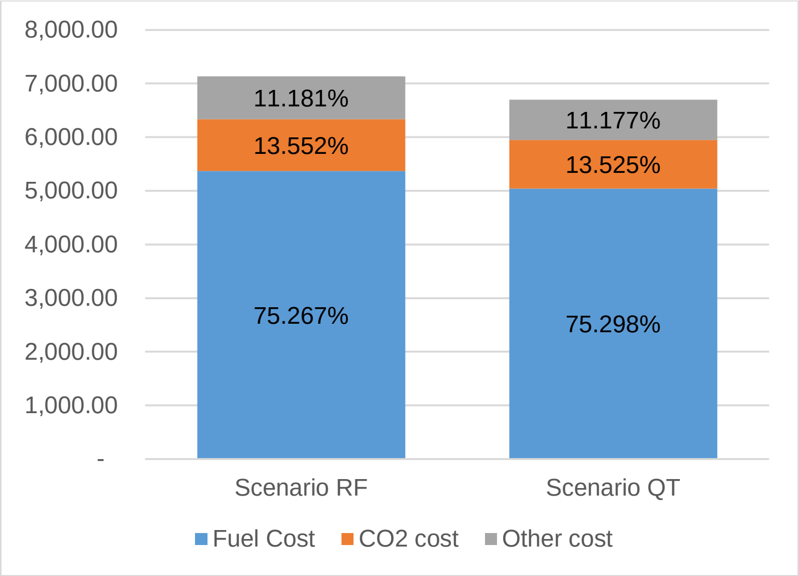


Figure 17: Cost structure with high CO_2 price
Source: Own elaboration

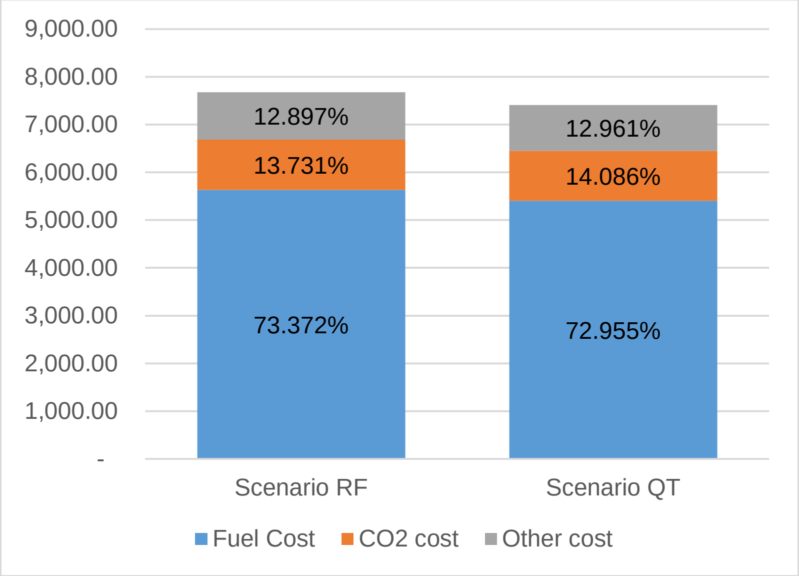


Figure 18: Cost structure with low CO_2 price
Source: Own elaboration

5.4.5 Summary

Comparing with the Reference Scenario, for diversified promotion on RES (QT):

- The generation cost will be 4.95% lower with high CO_2 price and 3.52% lower with low CO_2 price in 2030.
- The market price could be 0.77% higher with high CO_2 price and 5.98% higher with low CO_2 price.
- The congestion rage of interconnection will decrease by 1.67% with high CO_2 price and 1.71% with low CO_2 price.
- The CO_2 emission will be 6.32% lower with high CO_2 price and 1% lower with low CO_2 price in 2030.
- Fuel import dependence will be reduced by 0.79% with high CO_2 price and 0.57% with low CO_2 price.

6 Conclusions and further research

6.1 Conclusions

While the EU is getting closer to its climate and energy targets for 2020 (EC, 2015), it has recognized the necessary of an integrated policy framework for the left 10 years up to 2030. So the former EC launched communication “A policy framework for climate and energy in the period from 2020 to 2030” and Comminication “Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy” in order to set the basis for the 2030 objectives supported by the EC at the end of 2014(EC): At least 40% reduction of greenhouse gas emissions; At least increase to 27% for the share of renewable energy; At least raise the energy efficiency by 27%; 15% electricity interconnection target.

Now the debate is moving from strategy to action, from long-term vision to actual policies and regulations, looking for the most appropriate tools and mechanisms to get the most effective, efficient and equitable manner in order to reach the targets.

This thesis aimed to modestly contribute to this debate by:

- Developing a simplified model of one of the relevant electricity markets in Europe, the Iberian electricity market (MIBEL), which could be eventually used as a tool for assessing the effects of potential European energy and climate policies in the electricity sector;
- Running a first hypothetical case study with this model in order to test it, and show some of their potential uses when assessing European energy policies

Thus, the first step of this thesis has been to formulate a deterministic mixed integer linear optimization problem to compute the minimum cost dispatch of the Iberian power system in a set of different scenarios. The main characteristics of this model are:

- One-year scope and hourly market clearing combining medium-term horizon simulation with short-term operation details of Unit-Commitment.

- Optimization of total system costs calculated as the sum of generation costs (fuel cost, CO_2 emission cost, operation and maintenance cost, start-up cost and taxes) plus non served energy costs

- Modeling of operating constraints (generation-demand balance, spillage, interconnection between Spanish and Portuguese markets and logical start-up and shut-down constraints) and technical constraints (coal, CCGT and nuclear groups maximum and minimum power output, hydro and pumping maximum output and production constraints, etc.).

- Representation of eleven different technologies including nuclear units, thermal units, large hydro units, pumping storage, and technologies under regulated retribution schemes.

- Use of hourly profiles for the calculation of hourly demand non-dispatchable technologies production and interconnection flows between MIBEL and other power systems.

Once the model was developed, a case study was designed in order to test the model while showing its potential uses when assessing effects in the MIBEL of different potential EU energy policies.

The case study was based on different scenarios on:

- CO_2 prices
- Renewable energy market shares in the Iberian electricity market

In order to achieve the 2030 targets, there are some variables which will be affected by European policies. For instance:

- CO_2 price will be affected by the specific policies and regulation on the European Emissions' Trading Scheme (ETS). Different policies and regulations are being analyzed in this regard such the so-called 'back-loading' or the market stability reserve.
- Renewable energy market share in the Iberian electricity market will be affected by the mechanism to be implemented for the sake of 'distributing' the renewable energy European target among the different Member States, and the corresponding national policies/regulation which will 'distribute' the hypothetical national target among the different energy sectors (i.e.: transport, heating, electricity).

Thus, the case study could contribute with a modest input to the debate on the most appropriate alternatives when designing these policies.

Notwithstanding, the objective is not to make policy recommendations at this stage, but just to show preliminary results on potential effects that should be further tested through further research and modelling sophistication.

In order to simplify the results analysis, the scenarios were organized as follows:

- A Reference Scenario has been considered with the following characteristics:

Scenario	Spanish national RES target	Spanish power sector RES target	Spanish power sector RES target – Technology distribution	Portuguese national RES target	Portuguese power sector RES target – Technology distribution
Reference	27%	47.8%	Wind & PV focus	37%	Diversified

- The Reference Scenario is compared first with two alternative scenarios which consider a higher and a lower RES target for the power sector :

Scenario	Spanish national RES target	Spanish power sector RES target	Spanish power sector RES target – Technology distribution	Portuguese national RES target	Portuguese power sector RES target – Technology distribution
HT	30%	53.1%	Wind & PV focus	35%	Diversified
LT	27%	40.3%	Wind & PV focus	37%	Diversified

- Finally, the Reference Scenario is compared with an alternative scenario which applies the same RES target for the power sector, but distributing it among the different potential technologies in a diversified manner instead of just focusing on wind and PV:

Scenario	Spanish national RES target	Spanish power sector RES target	Spanish power sector RES target – Technology distribution	Portuguese national RES target	Portuguese power sector RES target – Technology distribution
QT	27%	47.8%	Diversified	37%	Diversified

All those scenarios were run under high (44€/ton) and low (22€/ton) CO_2 price scenarios.

Main conclusions drawn from case study results were:

- Reference Scenario vs. HT and LT scenarios:
  With High CO_2 price:

   - High RES share target in the energy sector leads to 16.98% lower generation cost, 20.9% lower market price, 21.22% lower CO_2 emission and fuel import dependence reduced by 3.02% in 2030;
   - High RES target also leads to the congestion rage increased by 15.25% in 2030.
   - Low RES share target in the energy sector leads to 29.18% higher generation cost, 10.71% higher market price, 36.42% higher CO_2 emission and Fuel import dependence increased by 5.28% in 2030.
   - Low RES target also leads to the congestion rage decreased by 8.79% in 2030.

  With low CO_2 price:
   - High RES share target in the energy sector leads to 15.76% lower generation cost, 13.28% lower market price, and 17.55% lower CO_2 emission and fuel import dependence reduce by 2.78% in 2030.
   - High RES target also leads to the congestion rage increased by 11.23% in 2030.
   - Low RES share target in the energy sector leads to 27.63% higher generation cost, 18.17% higher market price, 31.52% higher CO_2 emission and Fuel import dependence increased by 4.94% in 2030.
   - Low RES target also leads to the congestion rage decreased by 8.24% in 2030.

- Reference Scenario vs. QT scenario:
  With high CO_2 price
   - Diversified renewable promotion in the energy sector leads to 4.95% lower generation cost, 6.32% lower CO_2 emission and congestion rage of interconnection decreased by 1.67%.
   - Diversified renewable promotion in the energy sector leads to 0.77% higher market price.

  With low CO_2 price

   - Diversified renewable promotion in the energy sector leads to 3.52% lower generation cost, 1% lower CO_2 emission, and congestion rage of interconnection decreased by 1.67%.
   - Diversified renewable promotion in the energy sector leads to 5.98% higher market price.

6.2 Further research

This thesis is just a first step in modeling and assessing potential effects of different EU energy policies on the MIBEL. This could open the door to further research both in terms of modeling and in terms of policy analysis. Next, some suggestions for immediate further research following the work done in this thesis are proposed:

- Further research – Modeling:
    - Formulation of the problem under imperfect competition assumptions
    - Endogenously calculation of interconnection flows between MIBEL and other power systems
    - Simulation of demand and non-dispatchable production under an stochastic approaches
- Further research – Policy analysis:
    - More detailed analysis of the scenarios of this thesis:
        - Analysis on electricity price volatility
        - Analysis on the balance between investment and generation costs
        - Analysis on changes in the operation of thermal units: variation on start-up and shut-down requirements and on the number of hours working at minimum load in a period
    - Different scenarios:
        - Different electricity demand scenarios (both in terms of level and profile) to reflect potential energy efficiency policies to meet the 2030 energy efficiency target.
        - Different scenarios of interconnection capacity between Spanish and Portuguese power systems in order to analyze potential generating costs reductions.

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Annex 1 Proportion of mixed pumping storage units and large hydro

Installed capacity of pure pumping storage units group and mixed pumping storage group units are simbolizad as *ICP* and *ICM*. Annual energy consumption of both groups of pumping storage units are symbolized as *ACP* and *ACM*, the full load hours (*FLHP*, *FLHM*) could be calculated by:

$$\mathrm{FLHP} = ACP/ICP$$

$$\mathrm{FLHM} = ACM/ICM$$

By dividing annual consumption of mixed pumping storage units group with full load hour of pure pumping storage units group, namely to assume if mixed pumping storage units group works as pure pumping storage units to generate the same amount of electricity, the equivalent installed capacity, symbolized as ICM2P could be obtained.

$$\mathrm{ICM2P} = \mathrm{ACM}/\mathrm{FLHP}$$

Then subtracting of ICM2P from ICM, is the left part of the installed capacity (ICM2Y) of mixed pumping storage unit group that work equivalently as big hydro units.

$$\mathrm{ICM2Y} = \mathrm{ICM} - \mathrm{ICM2P}$$

Annex 2 Calculation of variable and fixed term costs of thermal generation units

Variable costs and fixed term costs have been calculated though the use of simplified linearized input-output curves linking the generation output and fuel. The representation is shown in the figure A2.1 and the intersection with y axis is the fixed term fuel consumption per hour for the unit.

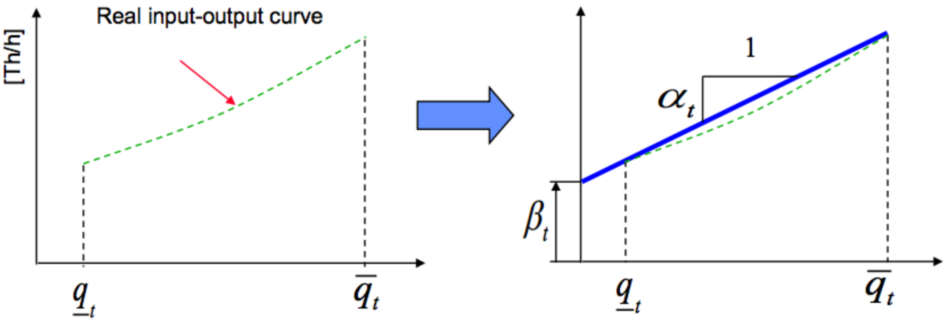

Figure A2.1: Thermal unit input-output curve linearization

Source: Mariano Ventosa

In Figure A2.1 above, the gradient of the curve is the variable costs related with fuel consumption for energy production, and then the variable cost of thermal plants is calculated with the following equations.

$$VarCost = \frac{\overline{Cost} - \underline{Cost}}{qmax - qmin} + OM + tax$$

$$\underline{Cost} = qmin / hr \times (1 - loss) \times fc + qmin \times cc \times er$$

$$\overline{Cost} = qmax / hr \times fc + qmax \times cc \times er$$

$$FiTCost = \underline{Cost} - \frac{\overline{Cost} - \underline{Cost}}{qmax - qmin} \times qmin$$

$\underline{Cost}$: Fuel and CO_2 costs when the unit is working at its minimum output [euros]

$\overline{Cost}$: Fuel and CO_2 costs when the unit is working at its technical maximum output [euros]

Tax: Taxes internalized in the variable cost [euros/MWh]

OM: operation and maintenance cost [euros/MWh]

Loss: losses rate when working at low temperature [p.u.]

Fc: fuel cost [euros/MWh]

hcr: heating rate [p.u.]

cc: CO_2 emission cost [euros/ton]

er: CO_2 emission rates. [ton/MWh]

FiTCost: No-load cost [euros/MWh]

This formula could model that the generation yield rate[30] slightly decreasing when the temperature decreasing, namely the temperature affects the performance of thermal units. For example, the fuel consumption to produce 1 MWh of electricity at different working temperatures may be different. While the O&M cost and taxes won’t affected by the yield rate.

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[30] Yield rate is the production and consumption ratio.

Annex 3 CO_2 price

A3.1 EU ETS overview

The EU emissions trading system (EU ETS) is introduced as a main instrument to tackle climate change issues, which is mainly focusing on taking cost-efficient ways to reduce emissions of greenhouse gas from energy and industrial sectors in the EU. It was issued with the Emission Trading Directive and came into force since 1st January 2005. EU ETS is the first and currently the biggest international GHG emission allowances trading system, which has covered more than 31 countries' 11000 power plants and industry plants, and airline industry as well. About 45% of the GHG emissions of the EU are covered by it (EC, 2015).

The mechanism used in EU ETS is designed with "cap and trade" principle. Cap means to set a top limit for the emissions amount of GHG by plants, factories and other installations. And the cap is going to decrease over time so that the total emission amount will be reduced accordingly. While trade means that each entity can trade, either sell or buy its emission allowances (EEA, 2014). For each year, companies must hold enough emission allowances to cover their emissions. Otherwise it may get a heavy fine. Companies gain flexibility by selling or keeping the amount of allowances beyond their emissions level so the EU ETS also has been designed to have a cost-efficient way to cut the GHG emissions. What's more, when taking a sufficient carbon price, it is going to incentivize the investment on clean and low-carbon technologies.

Trading period phase 1 was from 2005 to 2007. It was designed based on "learning by doing". Then from 2008 to 2012, it entered its phase 2. During phase 1 and phase 2, most of the subsidies were provided freely by governments with national allocation planning (NAPs) after being reviewed and accepted by the EC while few of the allowances were allocated though auction (EEA, 2014).

Since 2013, the EU EST has started its phase 3 (2013-2020), which contains many significant changes comparing with the first two phases because of the major revision approved in 2009[31]. A set of new rules set (EEA, 2014) for phase 3 are:

- Instead of national allocating planning in participating countries, a simple European common cap of emission subsidies has been applied since the beginning of phase 3 and this EU wide cup decreases annually.
- Currently the default method to provide subsidies is auctioning rather than free allocation. The share of subsidies to be allocated by auction is more than 40% in 2013 and this number is going to increase annually.

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[31] See Directive 2009/29/EC of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community

- Harmonized allocation rules are applied for manufacturing industry since it still receives allowances though free allocation, which is based on ambitious EU-wide benchmarks of emissions performance.
- NER300[32] is a provision of financing instrument to reserve 300 million allowances in the New Entrants' Reserve of the European Emissions Trading Scheme to subsidize the innovative technology for renewable energy employment and carbon capture and storage (CCS).

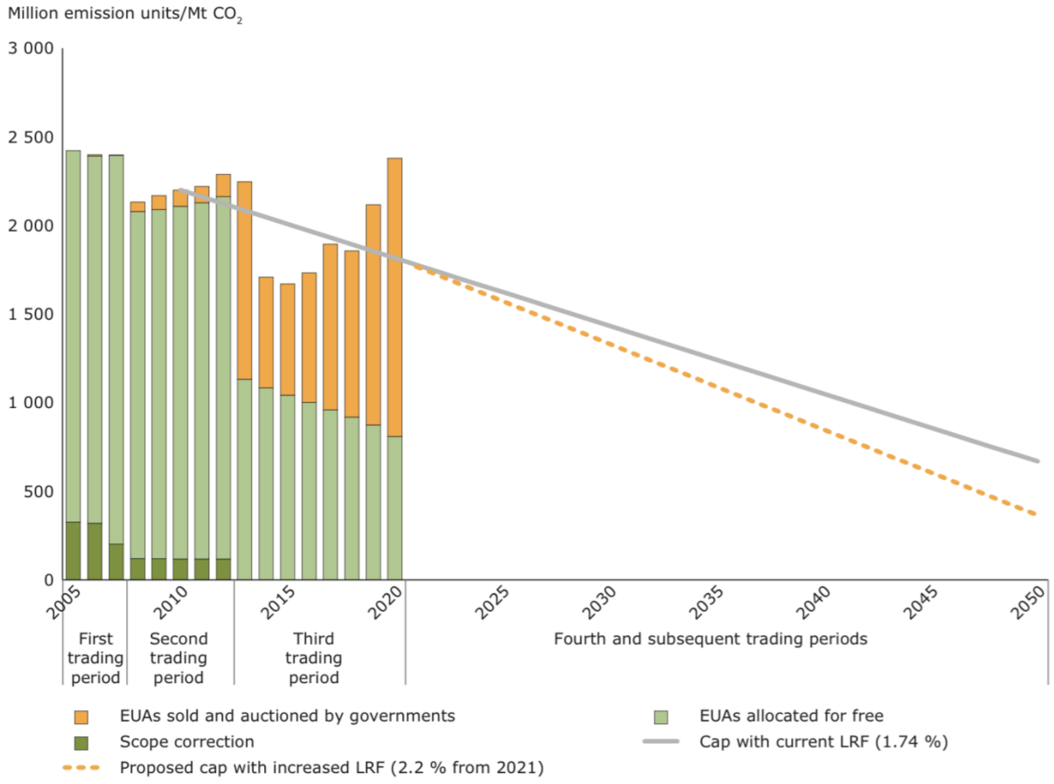

Figure A3.1: EU ETS caps up to 2020 and policy proposals up to 2050
Source: EEA, 2014e and 2014f; EC, 2013d

However the current situation is that the economic crisis and high imports from international credits lead to an increasing surplus of allowances. At the beginning of phase 3, there were almost two billion allowances surplus (EC, 2015c), which has significantly weaken the carbon price signal to transfer to a cost-efficient low carbon system.

The cap is set based on the target of 21% emissions reduction in ETS part in 2020 compared with 2005 level which is in accordance with the EU target of 20% emissions

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[32] See because Article 10(a) 8 of the revised Emissions Trading Directive 2009/29/EC

reduction compared to 1990 level (EEA, 2014). Taking into account the huge amount of surplus of allowances, from phase 3 the cap keeps decreasing with a linear reduction factor of 1.74%[33]. ETS emissions of EU will have to be decreased by 43 % from 2005 to 2030 in order to contribute cost-efficiently to the accepted 40% reduction target set out in the 2030 framework for climate and energy policy (EEA, 2014), and the average factor to reduce the cap will increased from 1.74 % to 2.2 % after 2021 (EEA, 2014), seen in figure A3.1.

A3.2 "Back-loading" of auctions and market stability reserve

While dealing with the challenge of surplus of allowances increase mainly caused by the economic crisis, which disturbs carbon market normally functioning with a short term perspective and hinders the achievement of emission reduction target in the EU ETS cost-efficiently with a long term perspective, the EU has taken actions: “Back-loading” of auctions and market stability reserve.

An amendment of the Auctioning Regulation so called “Back-loading” is proposed to postpone the auction of 900 million allowances from the early period of the phase 3 and then will release this amount of allowance back into the market in the late years of phase 3. So the total amount of allowance is not going to change but the distribution of the allowances within the period has been modified: 400 million, 300 million and 200 million of allowances are respectively reduced in 2014, 2015 and 2016[34]. It is implemented in the amendment to the EU ETS Auctioning Regulation (EU, 2014e)."Back-loading" of auctions is a temporary measure and it aims to deal with the imbalance between demand side and supply side in the carbon market and to reduce the volatility of the price from short term perspective, which has been demonstrated in the proportionate impact assessment (EC, 2012a).

Taking into consideration that the "back-loading" is only a short-term measure, the establishment of a market stability reserve though the structure reformation of EU ETS has been proposed by the EC. This aims to build a more balanced market, where the carbon price driven by mid-term and long-term GHG emission reaction and to increase the resilience of the system by adjusting the auction amount (EEA, 2014e). The measure of stability reserve will start from 2021 and the mechanism is when the surplus is over 833 million allowances, the coming allowance is going to be put into a reserve and until either the surplus is lower than 400 million allowances or it reaches the price threshold, the allowances in the reserve are going to be released (EEA, 2014e). It will completely work following the rules without being intervened by the Commission or by any

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[33] 1.74% is coming from the average cap from 2008 to 2012.

[34] See COMMISSION REGULATION (EU) No 176/2014 of 25 February 2014

Member State. The legislative proposal of market stability reserve (EC, 2014e) is presented in January 2014 to require approve from Council and the European Parliament to become law.

To conclude, the adjustment of linear ruction factor of EU GHG emission cap, the "back-loading" auction and the market stability reserve are the three main methods to reduce the emission allowances surplus in short term, to build up an emission allowances market with more resilience and to provide the appropriate carbon price signal to transfer to a cost-efficient low carbon system in the mid- and long-term.

A3.3 Carbon price in 2030

Since up to 2020, the "back-loading" of auctions in phase 3 is the only mechanism applied during this time period that will drive the carbon price changing and has been approved by the Parliament and Council though an amendment to the ETS Directive in December 2013 (EC, 2013), in this study the carbon price for 2020 is going to be set only considering the "back-loading" auctions during phase 3 as relevant policy.

In the proportionate impact assessment, the Commission has studied the potential impacts of "back-loading" on the carbon price. It has been mentioned in this document that it is analytically difficult to assess the impacts on the carbon price signal over phase 2 and 3 due to many reasons (EC, 2012b). For example, the willingness of the industry (sellers) which largely holding the surplus of allowance will impact on the carbon price a lot. The premium (need to be determined) required by the sellers in order to hedge any potential risk in the future also influence the carbon price. The impact may also come from the relative drop in demand from hedging[35] (EC, 2012b).

Even though that the Commission is not able to forecast the short-term carbon price profile, some market analysts have used their own tools to do the projection of carbon price impacted by the "back-loading", which has been reviewed by the commission when they did this proportionate impact assessment.

For example, Thomson Reuters Point Carbon" has estimated the CO_2 price up to 2020 taking into considering the "back-loading" scenario, which amounts and distributed time line are in line with the one proposed by the Commission. So we have applied the result of the estimation of carbon price in 2020 from Thomson Reuters Point Carbon (TRPC, 2012) to our model.

Until so far, for year 2030 with the target of reducing GHG emission by at least 40% below the 1990 level, there is no available projection on price estimation in accordance with the actions that the EU is proposed. What we have done is to study the scenarios in

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[35] Explained with more details in Staff Working Document on the functioning of the carbon market

Impacts Assessments of "a policy framework for climate and energy in the period from 2020 to 2030"(EC, 2014) and apply the projection of CO_2 price from the scenarios that are the most similar to 2030 target set already.

In the impacts assessments, firstly by using PRIMES, GAINS and other related models plus the comments from Member States experts, the Commission firstly started from constructing the New Reference Scenario, which reflects current trends by assuming all the policies adopted by late spring 2012 are fully implemented. Table A3.1 shows the New Reference Scenario results of GHG reduction and primary energy savings compared to the baseline in 2030 Table A3.1.

After that, they have made an assessment of other 7 scenarios of combining different targets and ambition levels on policy options for targets and measures. Among those additional scenarios, the CO_2 price estimated in scenario GHG40 and GHG40/EE has been applied in our model due to their targets and the final target are very similar comparing with other scenario shown in .

Both of them are under enabling conditions, which under an assumption that strong policy commitment on facilitating GHG emissions reduction in a term of 2050 (EC, 2014). These enable conditions are assumed to start to function before 2030 even though they are designed to bring the changes to the energy system after 2030. The Carbon price in our study is going to in line with the projection under these two scenarios as high and low carbon price options.

Scenario	GHG 2030 vs 1990	RES 2030 (% final EN.Cons.)	EE 2030 (change vs 2030)
Reference Scenario	-32.40%	24.40%	-21.10%
Enabling conditions			
GHG40	-40%	No pre-set target (26.5%)	No pre-set target (-25.1%)
GHG40/EE	-40%	No pre-set target (26.4%)	No pre-set target (-29.3%)

Table A3.1: Scenarios to assess main policy options with respect to targets
Source: Impact assessment