Possible scenarios for the electric system by 2050 - Portugal case

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Abstract

The European Commission and the EU member states resort to energetic models to support policy making and market design.

Energetic models are not carried out as a precise prediction exercise but as a means to outline possible scenarios and explore possible futures. This report aims to study possible solutions for the Portuguese electric system, with a carbon emission mitigation and an energetic dependency perspective in mind.

Considering security of supply, weighting together Portugal's current energetic dependency on fossil fuels, their future investment in renewable energy sources and the intermittency and irregular over and under renewable production, it is justifiable for Portugal to invest in storage technologies and/or other system adjustment mechanisms such as demand side management.

The most immediate storage solution for Portugal, as discussed extensively in many papers, news, and theses, is the electricity storage through pumped hydroelectricity.

In this work the main motivation is to find and compare to pumped hydroelectric storage, other storage technologies, study their adoption conditions and impact in Portugal's electricity generation cost.

The selected energy storage systems were lithium ion batteries and power-to-gas.

For all these storage systems was calculated and compared their impact on the electric energy generation cost, their impact on the country's energetic dependency and their impact on the emissions of CO_2.

It was also briefly discussed demand side management as a non-technological approach to reach the same emissions mitigation goal.

Pumped hydroelectric storage remains as a good storage solution however, in many aspects, a power-to-gas approach to the problem would overtake this first solution.

Within a P2G strategy were considered different scenarios which, depending on the desired outcome, presented different viable possible futures for the Portuguese electric system.

From an emissions mitigation and a renewable electricity point of view was concluded that Portugal is on the right track to achieve the desired goals.

Keywords: electric system, Pumped Hydroelectric Storage, Li-ion battery, Power-to-Gas, Demand Side Management, electricity generation cost

1. Introduction

Europe is taking measures to (1) decrease carbon emissions, (2) increase the share of renewable energy in the energy supply mix and (3) increase energy efficiency [1]

Considering the goals mentioned above, most of the efforts and discussions are naturally focusing on the renewable energy industry. Because each country has very distinct environmental, economic and social conditions, in the end all the strategies become very different from country to country.

Like many other institutions and companies, the European Commission and the EU member states resort to energetic models to support policy making and market design.

Energy-modelling is the virtual or computerized simulation that focuses on energy consumption, utility bills and life cycle costs of various energy related items.

It is also used to evaluate the payback of green energy solutions like solar panels and photovoltaics, wind turbines and high efficiency appliances. This simulation helps take any hard decision more easily and efficiently while saving both time and resources. [2]

The 3 pillars of energy supply - vital for any country economic development and social stability - are security of supply, price competitiveness and - as already mentioned - alignment with climate policy. If we consider the first pillar, weighting together the country's energetic dependency on fossil fuels and the intermittency and irregular over and under production of renewable energies, it is justifiable for Portugal to invest in development of storage technologies and/or other system adjustment mechanisms such as demand side management.

In this work, the main motivation is to find other storage technologies and compare them against pumped hydroelectric, studying their adoption conditions and impact in Portugal's electricity generation cost.

Two energy storage systems were selected to be compared against the pumped hydroelectric storage: batteries and power-to-gas.

For each of these storage systems, calculations will be done to determine its impact, both individual and comparative to one another, on the electric energy generation cost, as well as on the country's energetic dependency.

Finally, in parallel to the comparison between different technological strategies applied to the same all-time rules' scheme, it was considered relevant to invest some time looking at a totally different approach to achieve the goals of the energy transition.

This solution, known as "demand side management" sets the controlling systems on the demand side rather than on the supply side. However, this "non-technological" strategy would require huge legislative changes.

The goal of this work is to provide the required information, both technical and economical, for any decision maker to use and support his decision regarding the energy path to a carbon neutral country.

2. Energy transition goals and tracking progress

Other than laws there are also goals towards a more renewable energy mix, as well as a reduction of the greenhouse gas emissions (GHG), and an increase of the electricity use in the total energy consumption. These goals are generalized and applied worldwide, mainly through the Kyoto's protocol and Paris agreement, but then the specific goals are defined more locally. The European Union creates its own goals, which require the commitment of all countries in the EU, meaning that each country must then create its own goals for both energy mix and emissions mitigation.

The European Union's targets for 2020 are the following: [1]

- Reduce greenhouse gas (GHG) emissions by at least 20% (from 1990 levels)
- Increase the share of renewable energy to at least 20% of consumption
- Achieve energy savings of 20% or more

Given the environmental conditions in Portugal, it was possible for the country to draw goals that would over compensate the European ones: [3], [4]

- Ensure that 31% of the gross final energy consumption will be derived from renewable energy sources (RES) (60% of electricity produced, and 10% of the energy consumption in the road transport sector)
- Increase to 10% the electrical interconnections with Europe
- Increase the country's energy independence to around 74%
- Reduce the balance of energy imports by 25%
- Consolidate the industrial cluster associated with wind energy and to create new clusters associated with new technologies in the RE sector
- Reduce 18% to 23% the GHG emissions, compared to the 2005 values.

Aiming at 31% of RES in the final energy consumption by 2020, in 2015 Portugal had already reached an amazing 28%. One year later, that share rose 0,5%, which means that by the end of 2016 Portugal had already achieved 92% of the target. [5]

The European Parliament, however, is constantly setting new and more ambitious goals for the future. So far, they established the goals for 2030 and are adjusting the goals for 2050.

EU targets for 2030 are: [6]

- 40% cut in GHG emissions compared to 1990 levels
- At least 27% share of RE consumption
- Improvement in energy efficiency at EU level of at least 27% (compared to projections), to be reviewed by 2020 (with an EU level of 30% in mind)

- Support the completion of the internal energy market by achieving the existing electricity interconnection target of 10% by 2020, with the objective of reaching 15% by 2030.

Once again, the 2030 targets for Portugal are slightly different: [4]

- Ensure that 40% of the gross final energy consumption will be derived from RES
- Reduce 30% to 40% the GHG emissions compared to the 2005 values
- Increase to 15% the electrical interconnections with Europe.

For 2050, the European Commission developed a long-term strategy instead of specific targets, as it did for previous years. The purpose of this strategy is to create a vision and sense of direction.

The road to a climate neutral economy would require joint action in seven strategic areas: [7]

(i) Energy efficiency
(ii) Deployment of renewables
(iii) Clean, safe and connected mobility
(iv) Competitive industry and circular economy
(v) Infrastructure and interconnections
(vi) Bio-economy and natural carbon sinks
(vii) Carbon capture and storage to address remaining emissions

Never forgetting that the main goal is to have a climate change mitigation, assuring the security of energy supply and its price competitiveness, it is wanted, worldwide, that the share of renewable energy sources in electric energy increases, as well as the share of electric energy in the total energy consumption.

3. Strategies description

To improve the electric system, four different strategies are analysed: storage thorough pumped hydroelectricity and lithium ion batteries, power-to-gas and demand side management. Each one of them will be further explained, analysed and some practical applications of such strategies will be presented.

Energy storage technologies can support energy security and climate change mitigation goals by providing valuable services in developed and developing energy systems, as well as help to better integrate electricity and heat systems while playing a crucial role in the energy system decarbonisation.

3.1. Pumped hydroelectric storage

Pumped hydroelectric storage plants, also known as PHS, are a solution for storing energy, in artificial lakes created by dams. The water is pumped from a downstream reservoir to an upstream reservoir, usually when there is an excess of energy production at very low market prices, so, it can be later re-turbined, producing electricity in the hours it is most needed.

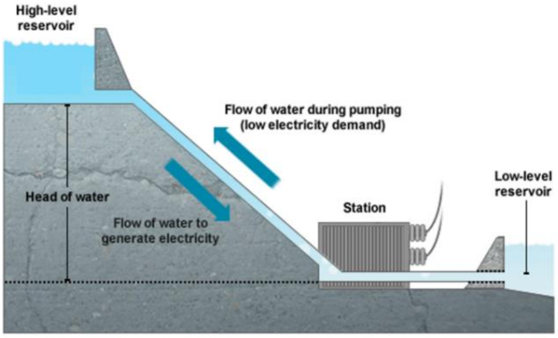

Figure 3.1 – Pumped Hydroelectric Storage scheme [25]

The efficiency of hydroelectric plants is 70-80% and varies with the technology used. However, when speaking of the whole pumped/turbined system, the efficiency of the pumped hydroelectric plant can drop down to 65-70%.

Nowadays, the investments in pumped hydroelectric plants can be either for totally new developments or reinforcements of previous ones, with addiction of pumps. This second approach implies smaller investment costs, which is a clear advantage to the project.

3.2. Batteries

A battery is composed of electrochemical cells, where chemical energy is transformed into electrical energy. [8]

There are different ways to classify batteries. Distinguishing them into primary and secondary is one of them. According to professor Fátima Montemor classes [9], primary (single-discharge) batteries have a finite quantity of reactants and once they are consumed, this type of battery cannot be used again. Secondary (multiple-cycle) batteries, can be recharged on the completion of discharge by forcing an electric current through it in the opposite direction, which will regenerate the original reactants from the reaction (or discharge) products. Therefore, electric energy supplied by an external power source is stored in the battery in the form of chemical energy. Consequently, the reactions happening inside a secondary battery must be chemically reversible. Finally, good rechargeable batteries will sustain a large number of such charge-discharge cycles.

The charge-discharge cycle of a battery is a succession of chemical reactions. When discharging, the electrons flow from the carbon material (anode), with Li+ insertion in the metal oxide (cathode), while when charging the reverse process takes place, with the electrons being supplied to the carbon material with Li+ insertion.

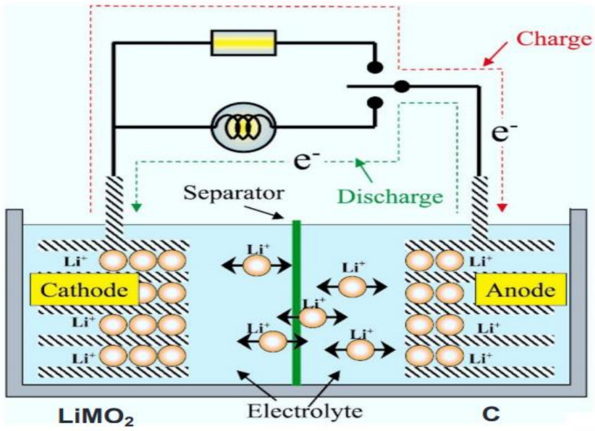

Figure 3.2 - Lithium-ion battery charge-discharge scheme [9]

The cathode used ($LiMO_2$) is representative since M represent any metal.

3.3. Power-to-Gas

The gas infrastructure can accommodate large volumes of electricity converted into gas, in case the supply of renewable power is larger than the grid capacity, or in case the electricity supply is greater than the electricity demand.

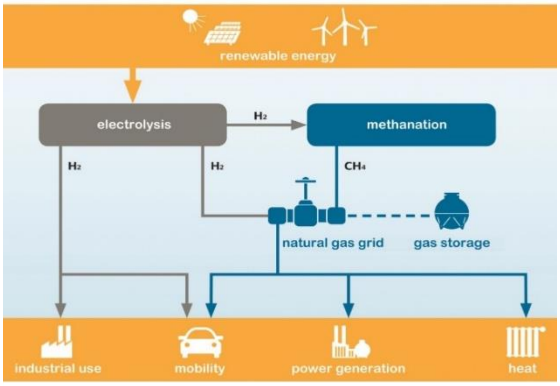

Figure 3.3 - Flowchart of a Power-to-Gas plant [26]

The Power-to-Gas principle is based on storing surplus energy from renewable sources by converting it into hydrogen (H_2) through electrolysis, or subsequently into methane (CH_4) syngas through methanation of H_2. As a result, power-to-gas enables the share of renewables in the energy mix to increase and provides an option for inter-seasonal long term storage of electricity, making this innovation a relevant strategy to achieve carbon neutrality by 2050.

The existing natural gas pipeline networks can also carry the resulting hydrogen and/or methane, facilitating the storage and transportation of these gases, which can then be blended with natural gas. [10].

This technology is of particular interest for Europe as its onshore and offshore natural gas infrastructure is well developed. In addition, the combined generating capacity of offshore wind farms could reach around 100 GW by the year 2030, while the PV capacity installed is expected to increase from 35 GW in 2012 to almost 60 GW in 2020, which P2G could give substance to. [11]

3.4. Demand side management

The term Demand Side Management (DSM) is used to refer to a group of actions designed to efficiently manage a site's energy consumption with the aim of cutting the costs incurred for the supply of electrical energy, grid charges and general system charges, including taxes, by deployment and use of improved technologies and changes in end user behaviour or energy practices.

The aim of these optimisation actions is to modify features of electricity consumption with reference to the overall consumption picture, consumption time profile, contractual supply parameters (contractual power and grid connection parameters) in order to achieve savings in electricity charges. [12]

Figure 3.4 schematically explains demand side management starting from the bottom, where electricity producers dictate the amount of available electricity, escalating all the way to the top, consumers, where they conciliate their activities to match the supply, while everything is controlled by an aggregated demand site control centre.

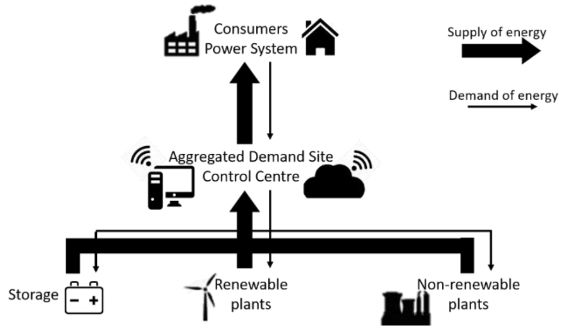

Figure 3.4 - Schematic explanation of demand side management

The consumers would be incentivised to shift their consumption away from peak periods since those are the moments non-renewable plants are most definitely required to produce energy and when electricity's price is the highest.

4. Methodology and data

As a reference scenario, for Portugal, it was used the EU28: Reference Scenario (REF2016) [13].

Using the data from the European Commission was made an energy model aiming to simulate possible futures for the Portuguese electric system through the installation of different storage technologies.

4.1. Reference Scenario

In an attempt to understand how the values presented in the EU Reference Scenario were obtained, it was calculated the impact of each source of energy given (hydro, wind, solar, coal, oil, gas and biomass) in the final overall energy generation cost.

Table 4.1 - Most relevant parameters used and calculated

Parameter	Units
Inestment cost	k€/MW
Gross electricity generation	GWh
Net generation	MW
Capacity factor	[-]
LCOE	€/MWh
Production cost	k€
Electricity generation cost	€/MWh
Decommission cost	k€/MW
CO_2 emissions	Mton
CO_2 emissions from electricity generation	tonCO_2/GWh
Carbon tax	k€/ktonCO_2

The capacity factor of a power plant is the ratio of its actual output over a period, to its potential output if it were possible for it to operate at full nameplate capacity indefinitely. This parameter varies greatly depending on the type of fuel that is used and the design of the plant.

The LCOE determines how much money must be made per unit of electricity (kWh, MWh etc.) to recoup the lifetime costs of the system. This includes the initial capital investment, maintenance costs, the cost of fuel for the system (if any), any operational costs and the discount rate. [14]

When comparing conventional fossil fuel systems such as coal-fired power plants and natural gas power plants with renewable systems such as solar, wind or nuclear, a LCOE analysis can tell which is the most viable system to implement.

The CO_2 emissions from electricity generation are also different depending on the fuel used. It was added a carbon tax of 30 € per tonne of CO_2 [15] emitted which was only applied from 2020 forward.

4.2. Strategies

As a first step for the energetic strategies' calculations it was assumed that there is a relation between Portugal's electricity exports and its electric generation from solar and wind. This correlation was calculated, and once discounting the electricity imports, it was obtained the amount of electric energy surplus.

Its was from the electric energy surplus that the strategies calculations were made.

4.2.1. PHS

Studying the impact of pumped hydroelectric storage for the electric surplus on the final electricity generation cost, is made a sensitivity analysis where is considered (i) the whole PHS investment as new ones and (ii) the whole PHS investment as power upgrade. This investment differentiation creates a final cost range. The LCOEs used were 66,94 €/MWh for new PHS and 33,47 €/MWh for power upgrade PHS.

4.2.2. Batteries

The Levelized Cost of Storage, usually referred as LCOS, aims to provide a robust, empirically based indication of actual cash costs and revenues associated with leading energy storage technologies, which leads to a preliminary view of project feasibility.

Following Lazard's report ([16]), the batteries being taken into account in this work are in-front-of-the-meter utility scale batteries, which are energy storage systems designed to be paired with large solar PV (or wind farms) facilities to improve the market price of solar generation, reduce solar curtailment and provide grid support when not supporting solar objectives. Their estimated LCOS is 108,5 €/MWh.

To completement the study on the impact of Li-ion batteries implementation in the total electricity cost a sensibility analysis was made on the LCOS for these batteries.

4.2.3. Power-to-gas

According to the European Power-to-Gas ([17]) the current natural gas grid can accept up to 20% of hydrogen in the mix without requiring any additional cost to upgrade nor change the already existing natural gas pipelines. This means, if the production of H_2 is smaller than 20% of the NG mix, then the whole H_2 production is what can be avoided in NG imports however, if the production of H_2 is greater than the 20% the NG grid can support, then the natural gas avoided imports are only 20% of original imports and the surplus of hydrogen produced can be exported, at a market price of 48,5 €/MWh ([18]).

The net cost for power-to-gas is the difference between the production cost for H_2, with an LCOE of 150 €/MWh ([19]), and the natural gas import's savings whose market price is 23 €/MWh ([20]).

To complement the study on the impact of a power-to-gas strategy implementation in Portugal it was made a sensibility analysis based on the non-decommission of the natural gas plants, as well as a sensibility analysis on the LCOE for power-to-gas.

In a non-decommission case, the generation of electricity had to be readjusted since it was assumed the country does not need more electric energy than the one that was originally designed by the Reference Scenario [13]. This means that some originally predicted investments can be avoided. However, in some cases there is still an excess predicted generation compared to the predicted generation, which was then assumed as electricity exports at a 50 €/MWh ([21]) market price.

4.2.4. Demand side management

The demand side management is more of a legislative measure than a technological one, so it would not be as simple as the previous strategies to calculate the impact on the electricity generation costs through the implementation of such strategy. Nevertheless, based on a smart meter project implementation in France [22], it was estimated an investment cost for Portugal.

It is assumed that smart meters have a lifetime around 10 years. So, it was created 10-year ranges between 2020 and 2050 to compare the smart meters investment with the investment for the strategies calculated.

5. Results and discussion

5.1. Reference Scenario

The electricity generation costs from the given reference scenario and the electricity generation costs calculated aiming to meet the values given are compared, in Table 5.1.

Table 5.1 - Estimated electricity generation cost for Reference Scenario, Calculated Reference Scenario (New PHS) and Calculated Reference Scenario (Power Upgrade PHS) (w/ carbon tax)

[€/MWh]	Reference Scenario	Calculated Ref Scen (New PHS)	Calculated Ref Scen (Power Upgrade PHS)
2000		62	
2005		71	
2010	73	84	
2015	91	89	87
2020	105	95	90
2025	109	93	87
2030	100	96	90
2035	94	95	89
2040	86	86	80
2045	85	83	77
2050	78	84	77

When comparing the calculated impact on the electricity generation cost with the given electricity generation cost on the Reference Scenario, the most accurate hypothesis is the one that assumes all hydroelectric investments as being new plants. For that reason, from this point forward, this will be the cost used as the calculated reference scenario for future comparisons.

5.2. Strategies

Table 5.2 presents the estimation for electricity surplus. As mentioned before, the elctric energy surplus will be the amount of energy used in the calculations for any possible future storage technology.

Table 5.2 - Electric Energy Surplus from RES

[GWh]	Electricity Surplus
2020	1973
2025	1976
2030	6365
2035	5905
2040	7587
2045	9399
2050	11749

5.2.1. PHS

The electricity generation cost is constantly increasing once the hydroelectric plants are used as storage technologies.

Table 5.3 - Estimated electricity generation cost for PHS strategy

[€/MWh]	New PHS	Power Upgrade PHS
2020	97	96
2025	96	94
2030	106	101
2035	111	103
2040	109	98
2045	115	99
2050	126	105

As a result of this technological decision, the electricity cost would increase between 19% to 42% from the 2015 values, since the implementation of the strategy is due 2020.

5.2.2. Batteries

The current LCOS for Li-ion batteries (108,5€/MWh [16]) is very high which makes this a economically non-viable solution. For that reason, it was calculated how the electricity generation cost would vary if the LCOS were 80 €/MWh or even 50 €/MWh.

Even though the likelihood of the LCOS dropping to such values is very low, these values were chosen for a sensibility analysis purpose only.

Table 5.4 - Estimated electricity generation cost for lithium-ion batteries strategy

[€/MWh]	LCOS 108,5	LCOS 80	LCOS 50
2020	99	98	97
2025	100	98	96
2030	117	111	105
2035	127	118	109
2040	133	121	107
2045	148	131	117
2050	170	147	123

The electricity generation cost decreases when the batteries' LCOS decreases however, the LCOS is not yet small enough to make this solution alone a viable one. In the batteries' scenario, the electricity generation cost is constantly increasing over the years, reaching costs as high as 170 €/MWh, whereas in the calculated reference scenario it is predicted a maximum electricity generation cost of 96 €/MWh in 2030.

If batteries, as they are, with a LCOS of 108,5 €/MWh were implemented the final electricity generation cost in 2050 would increase by 91% comparing with 2015 electricity generation cost, before batteries were implemented. However, if the LCOS were to decrease to 80 €/MWh or 50 €/MWh, the increase in the electricity generation cost would be only around 65% and 38%, respectively, compared to 2015 cost.

5.2.3. Power-to-Gas

In this strategy, the electricity surplus is used to produce H_2, and so, the H_2 produced is always the same no matter what sensibility analysis considered.

In a situation where the natural gas plants are going to be decommissioned, as the Reference Scenario predicts, Portugal could be capable of exporting H_2 from 2045. This would mean the electricity generation cost could decrease by this transaction and consequently, Portugal would even save money from the decrease import dependence on natural gas.

In this first power-to-gas scenario, the electricity generation cost would increase 62% in 30 years.

If Portugal would produce their own H_2 to use it in their natural gas grid, then it could be an advantage not to decommission the plants, as it is planned, or at least to delay that same decommission. For this case was calculated the impact on the electricity generation cost if (i) there were no natural gas plants decommission at all and (ii) if the decommission would be delayed, as in to decommission starting in 2040.

In these scenarios, the gross electricity generation would increade, and assuming the predicted generation is enough to fulfil the country's demand, then it would be necessary to adjust this electricity generation, to which, the approach adopted was not to invest in the originally predicted new renewable capacity.

The power-to-gas strategy allows to export both electricity and H_2 that neither the PHS nor the Li-ion batteries strategies allow These exports translate in earnings that help ease the final electricity generation cost.

Table 5.5 - Electricity generation cost for different P2G decommission strategies

[€/MWh]	w/ Dec	w/o Dec	w/ Dec 2040
2020		99	
2025		100	
2030		115	
2035	125	123	
2040	130	124	123
2045	143	121	119
2050	161	129	127

When decreasing the LCOE for P2G, the electricity generation cost decreases significantly, making the costs very competitive. The calculated costs can even be lower than the predicted ones by the Reference Scenario.

5.2.4. Demand side management

In France was implemented a smart meter project ([22]), where they installed 35 million smart meters with an investment of 6 000 million euros. This mean each smart meter has an approximate cost of 171,4 €.

Assuming the 35 million smart meters were for the whole population of France, 67 million inhabitants ([23]), when adapting for all 10 million inhabitants in Portugal ([24]), it is obtained 5,2 million smart meters, which would require an investment of 891 million euros.

6. Comparison between scenarios

Looking at all strategies and their final electricity generation cost, it is safe to say that the investment in lithium ion batteries to store the electricity surplus is not a viable solution to adopt country wide since there are solutions more cost-effective. This leaves PHS and P2G strategies left to compare.

When power-to-gas as a new strategy is presented with no further alterations to the electric system (P2G w/ Dec) the electricity generation cost increases almost as much as for the Li-ion battery scenario with a LCOS of 108,5 €/MWh.

However, if the goal is to implement such solution in the best way possible, then it may be worth considering not to decommission the natural gas plants or to delay the decommission. With such assumptions, the electricity generation cost decreases to equivalent values as the roof range of the PHS strategy.

Considering the sensibility analysis on the LCOE for power-to-gas, the electricity generation costs are compared with other strategies, and now, the best strategy to implement is no longer pumped hydroelectric storage.

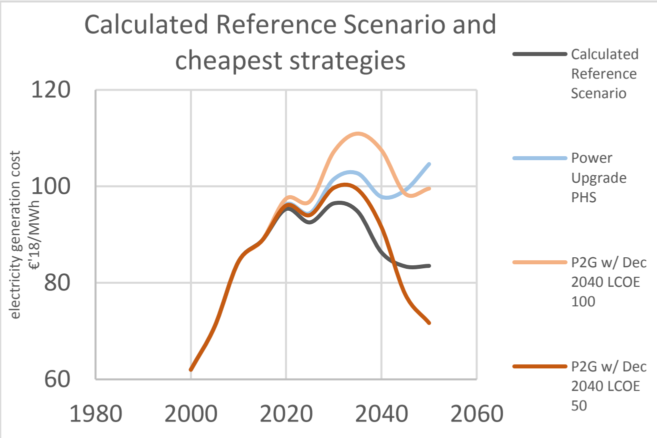

Figure 6.1 - Comparative impact of the less costly strategies and the calculated reference scenarios on the electricity generation cost

There are multiple criteria to evaluate which strategy is better to implement. The one most calculated up to this point was the generation electricity cost. Now will be put to evidence other important criteria such as (1) the share of electricity in the primary energy demand, (2) the import dependency and (3) the carbon dioxide emissions.

For storage strategies with the same electricity generation and net imports – PHS and Li-ion batteries -, the share of electricity in the primary energy demand is the same and higher than the share obtained from the calculated reference scenario. When decreasing the net imports – P2G w/ Dec – the share of electricity in the overall primary energy demand increases. However, P2G w/o Dec is the strategy with the highest electricity share, not only because the net imports in this scenario are the lowest but also, because the electricity generation in this scenario is the highest.

Another important criterion is the county's energetic dependency, and the scenario that provides the best independency is the scenario where Portugal consumes as much self-generated electricity as well as decreases as much as possible the net imports, which is P2G w/ Dec.

Finally, with the goal to reach carbon neutrality was calculated the CO_2 emissions for each strategy. For the strategies whose electricity generation do not differ from the electricity generation predicted in the Reference Scenario, the CO2 are not only the same but they are also the lowest. However, when considering a different electricity generation – P2Gw/o Dec and P2G w/ Dec 2040 – the emissions do not decrease as much since the naturas gas plant won't be decommissioned as predicted.

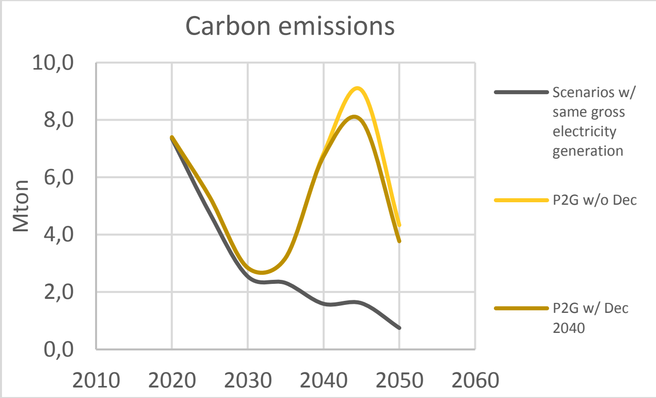

Figure 6.2 – Estimated carbon emissions, in Mton, from 2020

At last, was compared the investment in all the presented strategies with the eventual investment in smart meters. The calculated national expenditure for this investment is 891 000 000 €.

It was calculated, for each strategy, the national expenditure to implement the studied storage technologies in 10-year ranges between 2020 and 2050.

If the national expenditure for any of the strategies is greater than 891 M€, it means itwould be worth investingin smart meters. However, the calculations for smart meters are more of an estimation and, for that reason, it is widely recommended that before making any investment decision, the information regarding smart meters expenditure would be updated to more accurate values.

7. Conclusions

From the emissions mitigation and renewable electricity targets for 2020, Portugal set as a goal to have 60% of its electricity generation to come from renewable sources (the goal also says 31% of the gross energy consumption) and, by the calculations in all the scenarios presented in this report, by 2020 the renewable electricity mix would be around 71%, which means the goal is achieved. By 2030 however, the goal specification concerns the overall energy consumptions as it says 40% of Portugal's gross energy consumption comes from RES but, since through the scenario's calculations the RES share in the electricity generation is 87%, it can be concluded that Portugal is on the right track to achieve the desired goals.

The greenhouse gas emissions' reduction of 20% by 2020 and of 30% by 2030, compared to the 2005 values, are the goals Portugal set. Greenhouse gas emissions include carbon dioxide amongst other emission, and in this report was only possible to calculate the CO_2 emissions. Once again, compared to the 2005 values, by 2020 the CO_2 emissions are predicted to suffer a reduction of 68% and of 89% by 2030. These reductions contribute to a significant reduction of the GHG emissions, as desired.

The main goal of this report is to help a decision maker decide which energetic scenario is best to implement, depending on the desired outcome.

The desired outcome, evaluated as different criteria - electricity generation cost, share of electricity in the primary energy demand, share of RES in the overall electricity generation, imports dependency, CO_2 emissions and even incomes from both electricity and H_2 exports – ranks differently for each of the selected scenarios and strategies.

If the main decisive criterion is the electricity generation cost, then the best energetic option to adopt in Portugal would be a power-to-gas strategy considering the decommission of natural gas plants only from 2040 (P2G w/ Dec 2040), and secondly would be the implementation of pumped hydroelectric plants considering only a strategy of power upgrade (PHS Power Upgrade).

Finally, an implementation strategy of demand side management would only be worth considering if the investment in any other alternative would be higher than the implementation for DSM.

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