The effect of climate change on electricity planning

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ABSTRACT

The literature is vast in what regards the relationship between climate change (CC) and energy, especially in the sense of pointing this sector as an inducer of greenhouse gases (GHG) and demonstrating the importance of Renewable Energy Sources (RES) in mitigating these impacts. The relationships in the opposite direction, i.e. the way how CC could affect energy systems, are now being recognized as increasingly important by some international organizations and authors. This is precisely the focus of this paper, aiming to demonstrate how CC can affect RES and future electricity scenarios. The work addresses the particular case of Portugal and departed from the assessment of the impact of CC upon parameters of interest to hydro, wind and solar power production, according to international studies. This information was used as input of an optimization model for a long term power planning, resulting in the proposal of trajectories of the Portuguese electricity system under different CC assumptions.

KEYWORDS

Renewable energy sources; Climate change; power planning

INTRODUCTION

According to various studies, the temperature of the planet is increasing, sea levels are rising, glaciers are melting and precipitation patterns are changing. Extreme weather events are becoming more intense and frequent. Certain guidelines predict a rise in temperature and a decrease in annual precipitation particularly in south Europe and consequently in Iberian Peninsula [1, 2]. These changes will have a strong impact in energy services and resources. For example, changes in rainfall can lead to a reduction of water available affecting hydro production. Also, extreme events can disrupt production and effect structural integrity. Renewable Energy Sources (RES) availability and potential will be seriously affected because they depend primarily on weather conditions (temperature, solar radiation, wind speed, precipitation) [2,3]. These studies revealed the high importance of this topic, but demonstrated also the complexity of the research process and the need to further explore it for different regions and electricity systems.

The assessment of vulnerability and impact of CC scenarios in the energy sector represents important information that should support energy electricity planning decisions in the future. Strategic electricity planning should learn from past development but must also adapt historic data to future projections. This requires studying the present resources and planning for the addition of new power plants according to the forecasted demand requirements, the technical restrictions and possible environmental commitments. To support planning decisions the use of models frequently translated in software tools is required. These models can be particularly

helpful for assist in creating different scenarios and in analysing the impacts that projections in external factors such as CC have on the electricity system design and overall performance.
The question of CC and electricity planning is particularly challenging for the case of Portugal, a southern European country where electricity is mainly generated from hydro, thermal and wind power and where the share of RES is expected to increase in the following years. This paper addresses then two major questions: How much is CC likely to affect the RES hydro, wind and solar power potential in the Iberian Peninsula? Regarding costs and emissions, which scenarios can be considered optimal for future power systems' expansion under CC considerations?

The impacts of CC on the design of strategic power scenarios will be analysed resourcing to the sustainable electricity planning model (SEPP) described in Ref. [4] and adapting it to this research requirements. The case of Portugal will be addressed aiming to build future scenarios for the electricity sector, taking into consideration the forecasts for the sector constrained by CC projections for a 10 years planning period.

SEPP MODEL

The SEPP model allows to design optimal strategic long term investment decisions departing from a cost optimization tool [4]. In the model, economic and environmental criteria are included in the objective functions, aiming to minimize total generation costs and environmental impacts. Economic aspects comprise investment and operation costs of power generation units, while environmental ones comprise the GHGs emissions, specifically CO_2. As such, the proposed model formulation takes into account both the economic and environmental cost and is defined by a set variables, parameters, equations and constraints. These equations represent a mix integer linear optimization problem (MILP) to be used for the analysis of energy system taking into account all the electricity power generation technologies relevant for the system under analysis. The model is translated in a general algebraic modelling system code (GAMS).

The approach used for SEPP model adaptation for the case under study included the following steps:

- Characterization of the Portuguese electricity system, used as the departing situation for the optimization problem. The model assumed then an electricity system close to the Portuguese one, presently relying mainly on coal, natural gas, hydro energy, wind energy, biomass, cogeneration and other RES in a much less extent.

- Characterization of the expected electricity demand for the next 10 years. Electricity demand was assumed to present a yearly increase rate of 2.3% [5].

- Selection of the electricity generation technologies to be considered for the future scenarios. Taking into account Ref. [5] assumptions and projections, the technologies included were large hydro power (dams and run of river), pumping hydro, small hydro power, wind power, solar power, coal and natural gas power.

- Characterization of the expected CC impacts for the RES resources included in the system. This characterization relied on a literature survey, focusing in particular in the case of the Iberian Peninsula and resulted on three CC scenarios: Low CC Impact, Medium CC Impact and Extreme CC Impact, as described in the next section.

PROPOSED SCENARIOS

The impacts of CC strongly depend on the geographical region. A few major outcomes of studies addressing the southern Europe can be summarized as follows:

- The production of hydroelectricity power technology is potentially the most affected one, especially in the case of southern Europe. The reduction of water availability can lead to decreasing production of hydroelectricity power. For Portugal, an increase in temperature and a decrease in precipitation is foreseen and a negative change in hydroelectricity production can be expected for the future.

- Changes in wind speed may have positive or negative impacts, taking into account possible increase or decrease in the wind speed. The number of studies assessing the impact of CC on wind power technology on southern Europe are scarce. However, some projections already assume that there will be a decrease in wind speed over Mediterranean Europe, including Spain. However, these changes heavily depend on the geographical aspects and wind power projections should be considered as highly uncertain for this work.

- The increase of radiation and decrease of cloudiness due to temperature increase can lead to an increase in the number of days of clear skies. These are the main factors driving the expected increase on the availability of the solar resource throughout the 21st century for southern Europe and in particular for Portugal.

Based on the revised studies, a set of CC impact scenarios were detailed for the 10 years period for Portugal. Table 1 describes these impacts, relating it with relevant parameters for the RES availability projections.

Table 1. Summary-table of scenarios for the 10 years planning period

RES	Parameter	Scenarios				Sources
		No CC impact	Low CC Impact	Medium CC Impact	Extreme CC Impact	
Hydro and Small Hydro	Precipitation	Without CC	- 3,3%	- 5%	- 7,7%	[1] [6] [7]
Wind	Wind speed	Without CC	- 5%	- 10%	- 15%	[8] [9]
Solar	Solar Radiation	Without CC	+ 0,6%	+ 0,8%	+ 1%	[10] [11]

The projection presented in Table 1 were used as inputs for the modelling. The following assumptions and simplifications of the approach should however be underlined:

- The undertaken literature review put in evidence the difficulty on reaching consensual values, due to the uncertainty on climate projections. Also, most of the projections are focused on very long run scenarios (50-100 years). In this work, a simple linear projection of these impacts was assumed to calculate the values for the 10 years period which represents a rather simplistic approach.

- The parameters used for the estimation of RES availability in the future were average precipitation for hydro power and small hydro power, wind speed for wind power and amount of solar radiation for solar power. No intra-annual seasonal changes were considered, meaning that the historical pattern was assumed to remain unchanged.

- Projections about temperature were not used in the model and no assumptions were made regarding the possible loss of efficiency of solar power plants.

For this study, the analysis departed from a base case scenario with the cost minimization model constrained by relaxed CO_2 maximum limits. A second scenario was defined, imposing not only the relaxed CO_2 maximum limits but also the inclusion of new wind and solar power in the system (RES scenario). Finally a third scenario was analysed now with tight CO_2 maximum limits (Low CO_2 scenario). Each one of these problems was then readdressed considering new inputs for the parameters according to the CC assumptions described above. The combination of these 3 scenarios with the 4 CC impact scenarios resulted in 12 combined scenarios.

Projections were made about the possible trajectories of the Portuguese energy system considering these 3 different CC scenarios and using the SEPP model [4]. The simulation exercise allowed obtaining values of CO_2, costs, electricity productions and installed electrical power for the 12 scenarios for a 10 years planning period, for the minimum cost objective function.

RESULTS

This section, presents the results of each combined scenario obtained by simulation of the assumed electricity system and resourcing to the model SEPP for the cost minimization over a 10 years planning period. Figures 1 to 3 summarize the main results for the last year of the analysis, including the share of electricity generation technology and the average cost of the system.

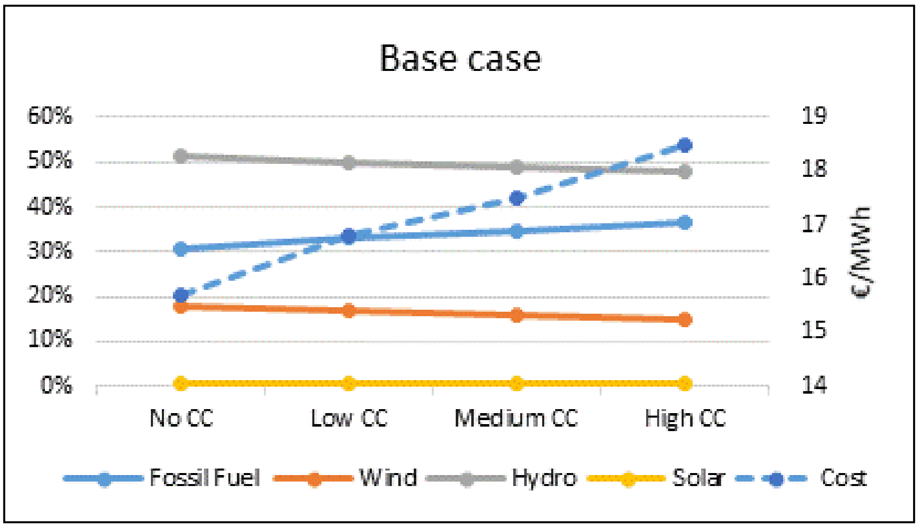

Figure 1. Base case scenario for different CC scenarios

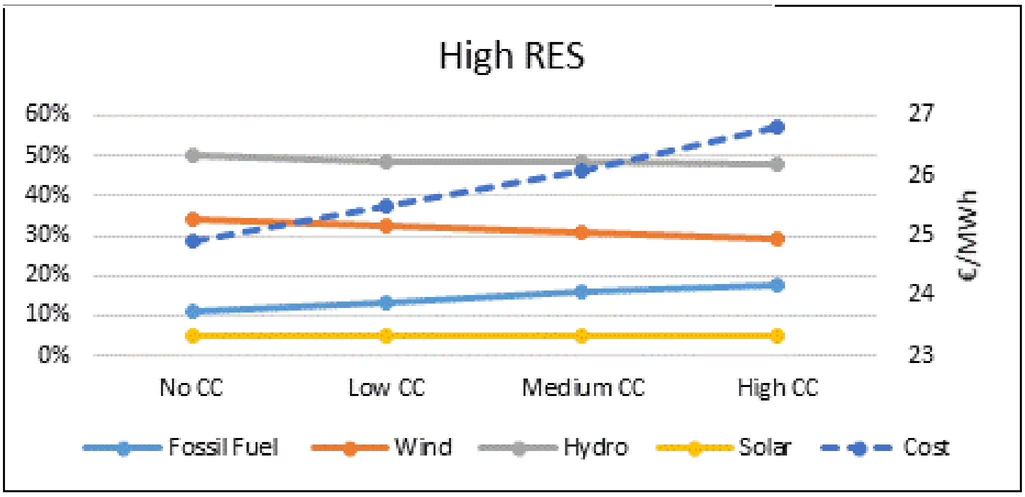

Figure 2. High RES scenario for different CC scenarios

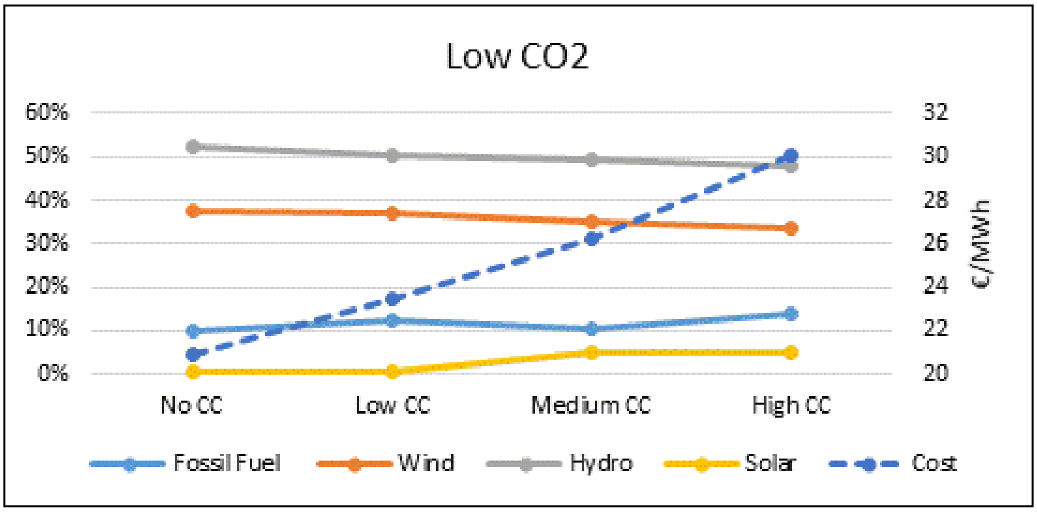

Figure 3. Low CO_2 scenario for different CC scenarios

The results of the simulation indicated that the effects of CC on electricity produced in Portugal will be mainly caused by the decrease in hydro and wind power potential and by the increase in solar power potential. Thus, it can be stated that as expected and as could be seen above, the hydro power output is always reduced under CC scenarios. The wind power also shows a reduction in the production of electricity in all CC scenarios compared to the respective non CC impact scenarios. The solar power shows a slight increase in the electricity production compared for CC scenarios comparatively to the reference scenarios. However, solar power contribution is quite reduced in all cases and in most cases thermal power plants are required to compensate the loss of hydro and wind power potential, either through the construction of new thermal power plants or a higher use of the existing power plants. In general, for CC scenarios, the optimization problem leads to solutions with higher installed power including not only RES but also natural gas or coal power, due to the reduction of hydro or wind power output.

Climate change is a key aspect to be taken into account during energy planning as under extreme CC scenarios, the share of wind power can be reduced between 2,6% and 5%, the share of hydro power can be reduced between 1,9% and 4,4% but the share of solar power can increase by 4,6% comparatively to the base case scenarios. Even for low CC scenarios the reduction of hydro and wind power is already evident, supporting the need to include these aspects on business evaluation and energy policy decision making.

Regarding costs, it can be stated that the greater the impact of CC on electricity production, the highest the electricity costs will be. This includes both investments, fixed and variable operating costs. Higher costs are obtained when the optimal solutions require the increase on installed power of more expensive technologies, such as solar power. The increase in cost is also driven by the intensification of fossil fuels consumption, in a way to compensate for the reduction of hydro or wind power. Under the base case scenario, extreme CC impacts can lead to an increase of 18% of cost comparatively to the non CC situation. However, this cost increase can even reach 44% if low CO_2 conditions are imposed to the electricity system, mainly due to the required higher reliance on solar power.

CONCLUSIONS

In this study the impact of CC on the electricity production potential for hydro, wind and solar was assessed for the case of the Portuguese electricity system, simulating different projections. Using the modelling tool SEPP, 12 scenarios of evolution of the electricity system were analysed, in order to assess the impact of CC on electricity production and on RES output. The study showed that the electricity sector is vulnerable to CC, but there are differences between the impacts on renewable technologies, according to the imposed limits on CO_2.

The modelling of the installed capacity in CC scenarios have revealed that the total installed power will not be significantly affected, changes are mainly on the energy source used under CC scenarios with medium and extreme projections. Under CC assumptions, RES power production, such as hydro, small hydro and wind will be reduced. The solar power output will increase with only a marginal impact on the overall electricity system. In general, for all scenarios RES share is always higher than the share of electricity produced from fossil fuels. This is mainly driven by the imposed constraints on the CO_2 emissions and RES share.

CC does not significantly impact the total amount of electricity production in 10 years, but will change the sources used. This happens because, for the sake of simplicity, the model did not take into consideration the CC impacts on the total demand and on the electricity consumption pattern through the year.

Finally, although the decrease in the availability and potential for RES electricity production is minimal in percentage terms some cautions should be taken when analysing the results. In fact, these percentage terms are relatively low as the number of years in the study is also small and relatively close today. CC impacts are expected to be particularly relevant in 50 or 100 years planning period and long term planning models must be developed under these assumptions. The work is proceeding addressing not only this long-term evaluation requirement but also aiming to assess and model CC impacts on the demand side and to evaluate how energy systems integration may contribute to mitigate these impacts on the electricity system.

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