Proposing an integrated assessment methodology to analyse the economic impacts of climate change on the renewable energy sector in Portugal

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ABSTRACT

Climate change is a major challenge faced by mankind. It results to a large extent from human action through the emission of greenhouse gases (GHGs), particularly from the energy sector. As concerns about the consequences of economic activity on the environment increase, studies about the economy-energy-environment system thrive, and integrated assessment approaches, which combine economic and climatic/biophysical components, emerge. Few studies focus on the renewable energy sector in the face of climate change – even less so for Portugal. This constitutes a gap in scientific research that hampers the formulation of informed environmental-economic policies for climate change mitigation and sustainability. Thus, our aim is to perform an integrated assessment of the impacts and feedbacks between climate change, natural resource availability (mainly water), the energy sector (namely hydropower) and the Portuguese economy, applying climate change and catchment modelling approaches to analyse the physical impacts of climate change, and partial and general equilibrium models to evaluate their economic consequences.

KEY WORDS: *Climate change; energy sector; renewable energy; economic impacts; integrated assessment*

INTRODUCTION

Climate change is a major challenge faced by mankind as it interferes with several domains of Earth and Life - the ecosystems, coastal areas, water, food production, health, human settlements and industry (in particular, the energy sector), and results, to a large extent, from human action due to the emissions of greenhouse gases (GHGs) to the atmosphere. In Europe, the main projected impacts of climate change are (IPCC, 2007): deepening the existing regional asymmetries of natural resources and increasing the risk of floods and erosion; loss of biodiversity, reduced snow cover and, consequently, winter tourism; increasing health problems associated with heat waves and wildfires; increasing ambient temperatures and droughts; and reducing water availability, which, in turn, will negatively affect summer tourism, crop productivity and hydropower potential. In southern Europe, the main projected impacts are increases in energy demand and heat waves (EEA, 2012a).

As stated by Stern, 2007, climate change is the greatest and widest-ranging market failure ever seen. To overcome its impacts, two broad types of policies can be implemented: adaptation (adapting to climate change impacts) and mitigation (reducing GHGs emissions). To date, societies have been adapting to climate change impacts and reducing their vulnerability to floods, droughts, etc., although some additional measures and policies are still needed (IPCC, 2007). Regarding the energy sector in particular, the IPCC advocates the improvement of energy efficiency, the use of renewable energy (RE) and the diversification of the energy mix. In what concerns mitigation, the IPCC, 2007, highlights the consensus and evidence about the economic potential for mitigation[1] of global GHGs emissions over the next decades that can offset their projected growth or even reduce them. Thus, succeeding in mitigation of climate change impacts implies to act over the economic sectors responsible for the major part of GHGs emissions, namely energy supply[2].

Energy issues vary considerably among countries and especially between developing and developed economies. While in the former the main questions are related to an increasing demand of energy, in the latter concerns refer to the improvement of energetic security and to mitigation, in order to reduce the energy sector impact in climate change. In these countries, renewable energies (REs) can have an important role on both: on the one hand, they can improve energy security as, when diversifying the energy mix of the countries, they reduce their dependence on imported energy sources; on the other hand, they also contribute to GHGs emissions reduction. Despite their present limitations (e.g. the early stage of some technological developments, the absence of competition on the supply and demand sides, and their variability in time and space; IPCC, 2011), REs

[1] The concept of 'mitigation potential' assesses the scale of GHGs reductions that could be made, relative to emission baselines, and is differentiated in terms of 'market mitigation potential' (which refers to private consumers and companies) and 'economic mitigation potential' (which reflects the perspective of society in terms of costs and benefits) (IPCC, 2007).

[2] In 2010, the energy sector was the first in the rank of emissions produced by economic sectors in the EU, accounting for nearly 60% of the total GHGs emissions (own calculation based on Eurostat, 2011).

constitute an important tool to mitigate climate change and to promote sustainable development.

Thus, even though energy supply sector is one of the main drivers of climate change (IPCC, 2007), considering, on the one hand, that almost no human need can be satisfied without energy services and, on the other hand, the sector's potential for mitigation of climate change impacts, the challenge faced by modern societies is to provide energy services with low environmental impacts and GHGs emissions.

The aim of this paper is to propose an integrated assessment of the impacts and feedbacks between climate change, natural resources, the energy sector and the Portuguese economy with the aim of analysing the economic impacts of climate change on the energy sector in Portugal focusing, in particular, on the renewable energy potential (namely hydropower) to mitigate climate change and promote sustainable development.

In the next section we describe the impacts of climate change on the energy sector, both on the demand and on the supply sides. In turn we review some existing studies and most common approaches to assess the economic impacts of climate change. Next, the proposed methodology is described and, finally, conclusions are presented.

SETTING THE PROBLEM

One of the most remarkable impacts of climate change is on freshwater quantity and quality (EEA, 2012a). Taking into account freshwater is an indispensable resource for human activities, the spatial distribution of the economic activities dependent upon water, namely agriculture, industry and energy production, are affected by climate change. Additionaly, according to the EEA, 2012a, some of the largest potential costs (and also benefits) of climate change in Europe are likely to occur in the energy sector, namely through negative and positive effects on future energy demand and supply (namely because low water levels in reservoirs limit hydropower production; EEA, 2012b).

On the demand side, the most studied impacts of climate change are those related with heating and cooling needs, which are associated to heating and cooling degree days[3] (Mideksa, 2010). Moreover, the demand for energy is also affected by economic and population growth that, necessarily, have to be taken into account in the analysis of the economic impacts of climate change on the energy sector. Conclusions are very similar between studies, usually reporting an increase in energy needs for cooling and a decrease of the energy needs for heating (e.g. Benestad, 2008; De Cian *et al.*, 2007; Eskeland & Mideksa, 2009; Mansur *et al*., 2008; Mideksa, 2010). In the EU, existing data show a reduced demand for heating (particularly in northern and north-western Europe) and an increased demand for cooling (particularly in southern Europe) (EEA, 2012a). Moreover, Considine, 2000, De Cian *et al*., 2007, and Eskeland & Mideksa, 2009, concluded that the increase in energy demand for cooling will be larger than the decrease in energy demand for heating – De Cian *et al*., 2007, estimated a 1.17% elasticity of demand for cooling purposes in warmer countries against a -0.21% to satisfy heating needs in colder places.

Concerning Portugal, Santos & Miranda, 2006, concluded that climate change will induce an increase in energy demand for climatization, as the reduction in energy demand for heating will not offset the increase in energy demand for cooling. It is anticipated, inclusively, a displacement of the peak demand from winter to summer as well as that the cooling season will shift from 8 to 10 months. Cleto, 2008, concluded the opposite, i.e., that there will be a strong reduction (47%) in energy demand because the decrease in energy demand for heating more than offsets the increase resulting from higher cooling needs.

But climate change is also expected to affect energy supply of all sources of energy production, particularly the yield of renewable energy systems (both because the availability of the energy sources may change and because they are sensitive to environmental parameters), and especially hydroelectric production (EEA, 2012a). Regarding hydropower, according to Mideksa, 2010, there are three major factors to be considered when studying the impact of climate change on production: changes in river flows, evaporation and dam safety. As to river flows, if precipitation increases/decreases due to climate change there will be a greater/smaller potential for hydropower generation; however, if river flow exceeds the capacity of built reservoirs consequences will be negative. In what concerns dam safety, it is as an important issue as climate changes are relatively abrupt. According to the EEA, 2008, the projected impact of climate change on precipitation and glacier melt indicate that hydropower production could decrease by 25% or more in southern Europe. Cleto, 2008, concluded that under a climate change scenario, the Portuguese potential for hydropower will be reduced.

Evidences of climate change in southern Europe (particularly in summer) are the decrease in river flows (as projected for Southern Europe) and the increase in the frequency and intensity of droughts, as a result of decreased precipitation and increased temperature (EEA, 2012a). This results in the decrease in water availability and crop yields, which will increasingly affect the hydropower sector through the combination of lower water availability and increasing energy demand. Examples of such evidences are the 40% decline in cereal production and hydroelectric power production resulting from the intense drought throughout the Iberian Peninsula during 2004–2005 (García-Herrera *et al.*, 2007), what forced Portugal to compensate for low hydro-electrical production by using fossil fuels (EEA, 2012a).

Moreover, climate change will induce an increased competition for water resources, especially in a context of combined decrease in precipitation and increase in ambient temperatures. Under such conditions river flows will be reduced and drought areas will be extended, namely in the Mediterranean basin (IPCC, 2007), so, trade-offs between different water uses (energy production, agriculture, energy crops, municipal uses) have to be carefully analysed.

LITERATURE REVIEW

Due to the magnitude of its impacts, both regional and sectoral, climate change has been widely studied by several disciplines - from natural sciences to engineering and to economics. From the economic point of view, many studies concerning climate change and its impacts are being carried

[3] Heating and cooling degree days correspond to the sum of negative/positive variations, respectively, of the current temperature in relation to a base temperature (i.e., when there is no need of heating nor cooling) over a period of time (Benestad, 2008).

out, some addressing the global economy, some focusing on specific regions or on particular economic sectors, and so on, and all using different economic approaches – each with their own peculiarities but also similarities. Examples of such approaches include Cost minimization (to achieve the cheapest way to produce a given level of output determined by a production function), Welfare optimization (to maximize the net present value of welfare across time subject to a set of economic constraints), Partial equilibrium (that focus on a particular economic sector, treating the remainder of sectors as exogenous, thus allowing a relatively high degree of disaggregation of the specific economic and institutional factors) and Computable General Equilibrium (CGE, which represent the whole economy as a set of linked sectors through a Social Accounting Matrix to model interrelations between productive sectors) (Pollitt *et al.,* 2010; Stanton *et al.*, 2009). In this section we review some of the existing research on the economic impacts of climate change on the energy sector, using different economic approaches.

Tol, 2002, applied a model of climate change to estimate the costs of climate change for 9 world regions for the period 2000-2200 on different sectors. In what concerns energy consumption, the author concluded that energy for heating will decrease whereas demand for cooling will increase, but both with small impact on GDP (below 1% and -0.6%, respectively). Bosello *et al.,*2007, used a CGE model of the world economy to analyze the impact of climate change on households' demand for energy in a context of perfect and imperfect competition in the energy sector, and concluded that in both cases climate change will increase demand for coal and oil and decrease demand for gas, oil products and electricity.

Eboli *et al.,* 2010, used a dynamic multi-regional CGE model of the world economy to capture the effects of climate change on agriculture, health, tourism, sea level rise and energy demand. The aim was twofold: to investigate the economic impacts of climate change on growth and income distribution and to assess to what extent considering climate change feedback on economic scenarios leads to significant changes on the estimates of GHGs emissions. They concluded that energy prices will decrease and that the global change on GHGs emissions resulting from the computed economic growth will be quite small and negative despite regional differences. The combination of almost constant production quantities in energy production industries (coal, gas, oil products and electricity) and the estimated decline of price means that the overall impact of climate change in the energy sector is a reduction of global demand associated with a quite rigid supply curve (Eboli *et al.,* 2010). The aggregate effect of climate change is negative but there are some regions, namely the EU, that will start by suffering a negative impact (around 2050) and that, in turn, will inflect and turn to be positive (around 2100). In what concerns energy demand, the authors refer to De Cian *et al*., 2007, who estimate a decrease in natural gas and oil demand on household demand of energy for heating needs as a result of climate change.

Ekholm *et al.,* 2010, studied the economic impacts of post-2012 climate policy in terms of mitigation efforts considering, among other sectors, industry and electricity, to which the model forecast a reduction in output due to demand-price elasticity and a decrease in the energy consumption due to improved efficiency in 2020. Marques & Fuinhas, 2011, performed a dynamic panel approach to analyse the commitment of 24 EU countries with RE in order to fight climate change and concluded that concerns about sustainability and climate change mitigation are not enough to motivate a shift to RE and that the traditional energy sources based on fossil fuels refrain the use of RE.

Concerning Portugal, Cleto, 2008, assessed the impacts of climate change on hydropower system and on residential and commercial energy demand with two main objectives: perceiving the impact of climate change on the energy system with the policy envisaged (PNBEPH)[4] and to evaluate to what extent projected hydropower investment contributes to satisfy energy demand requirements and CO2 reductions in a cost-effective way. In a scenario without climate change, primary energy supply exhibits a sustained growth especially due to increased efficiency and due to the share of renewable sources of energy in electricity production. Final energy consumption in the residential sector will tend to rise along the whole period whereas in the commercial sector the evolution, though positive, is not so linear. Installed capacity will also increase especially due to the penetration of renewables, which will account for 92% of the total installed capacity (mainly hydropower[5], wind and concentrated solar power). In a climate change scenario, primary energy supply remains similar to the baseline, but final energy consumption decreases, especially from renewables (the reduction of demand of energy will shrink their market). Concerning installed capacity, the model shows that when there is no obligation to accommodate existing policies there is less investment in new capacity (despite all scenarios point out to a full implementation of PNBEPH), which means that hydropower plants become less competitive and substituted by concentrated solar power plants. Cleto (2008) thus concludes that climate change has a very important impact on the energy sector, especially in hydropower profile (lower availability of water seriously compromises hydropower investment and electricity production from this source) and on demand (increases in temperature lead to an overall reduction of demand for useful energy), hence contradicting other results (Santos *et al.,* 2002) which point out the overall demand increase of energy due to increasing demand for cooling and negligible impacts on hydropower.

As shown, while the economic side of climate change has been widely studied, only few studies focus on the energy sector and/or adopt a truly integrated framework of analysis – even less so for Portugal. This points towards a significant gap in research, which needs to be addressed if we intend to fully understand the economic-environmental system and provide knowledge that must underlie informed policies. The methodology we propose, described in the next section, aims at developing an approach that simultaneously consider economic and environmental parameters in order to provide a comprehensive understanding of the impacts and feedbacks between climate change, the energy sector and the economy in Portugal, justified by the sector's potential to mitigate climate change effects, namely through the proliferation of renewable energies.

[4] PNBEPH - Plano Nacional de Barragens com Elevado Potencial Hidroeléctrico (2007)

[5] However, results show that the increase in hydro capacity beyond 2010 (63%) largely exceeds electricity production raise from this source (27%), which is to say that the most productive sites have already been built (Cleto, 2008).

METHODOLOGY

As concerns about the environmental impacts of economic activity and their consequences on sustainability increase, studies about the economy-energy-environment system flourish and become an essential tool for policy-makers. Nevertheless, it is frequent that the economic impacts of environmental issues, in particular those related to climate change, are analysed using strictly economic approaches, as shown in the previous section.

In these analyses, outputs of production processes that enter the environment (e.g. emissions) and their implications, such as pollution and climate change, are usually treated as simple externalities that are given a price which is considered in models. However, these pressures should be measured also in physical units in order to provide a full assessment of impacts, using specialised models such as climate change models. It is thus desirable to strengthen linkages between these models and macroeconomic frameworks, instead of focussing only on economic indicators, as argued by Pollitt *et al.*, 2010. These authors even identify some improvements for future research on sustainability, which also apply to the assessment of economic impacts of climate change. First, taking biophysical data into account in order to provide a link to environmental issues. Second, including resource use and availability (namely water).

Thus, to overcome the limitations imposed by a solely economic analysis of environment-related matters, we propose to apply an alternative and emerging methodology - Integrated Assessment Models (IAMs) - that simultaneously considers economic and natural (climatic, biophysical, etc.) principles and parameters in order to analyse the economic impacts of climate change on the renewable energy sector in Portugal, particularly on hydropower. These models are defined by the IPCC (1996) as "convenient frameworks for combining knowledge from a wide range of disciplines in order to conduct co-ordinated exploration of possible future trajectories of human and natural systems, development of insights into key questions of policy formation, and prioritisation of research needs in order to enhance our ability to identify robust policy options".

The proposed integrated assessment will be composed of four sequential stages:

- Firstly, we will analyse the effects of climate change on natural resources availability (namely water) as well as the range of possible impacts on watershed systems.
- Secondly, we will assess the consequences of such impacts on hydropower supply, at a regional scale, as well as corresponding production costs, installed capacity, GHGs emissions and final energy prices.
- Thirdly, we will develop and apply a CGE model for continental Portugal. Three major extensions to existing research using CGE models are contemplated: first, a more in-depth specification of the energy sector, with particular emphasis on REs; second, the inclusion of natural resources used in renewable energy production as production factors; finally, a spatial disaggregation at the regional level. To achieve so, we will improve the existing specification of the energy sector and include corresponding natural resources stocks (namely water) to determine current natural resources allocation/ demand between sectors (including energy, agriculture and end-users).
- Finally, we develop the abovementioned "integrated assessment model". This model will integrate the biophysical and economic modelling components – thus allowing for the analysis of the impacts of climate change on the energy sector in Portugal, for a specific energy type (hydropower) and region.

The proposed methodology aims to fill the lack of interdisciplinarity concerning the interactions between the economic and the environmental systems highlighted in the literature (e.g. Pollitt *et al.*, 2010; Mideksa, 2010, Nunes *et al*., 2008).

This integrated and comprehensive analysis of the energy-environment-economy system is expected to allow for further research on this topic, namely to understand how/to what extent climate change will affect the production and efficiency of hydropower and, thus, scrutinize to what extent EU goals for the share of renewable energy on energy mix may be compromised. The obtained results will also allow for an analysis of which energy policy options (concerning REs) may be undertaken in Portugal to minimize the negative impacts of climate change on energy production, and which instruments may be adopted to achieve the EU goals regarding climate change mitigation and sustainability.

CONCLUSIONS

Climate change interferes with several domains of Earth and life and is, to a large extent, caused by human action, especially through industry, transport and, above all, energy use. On the other hand, one of the most significant impacts of climate change is on freshwater quantity and quality. Thus, considering that freshwater is an indispensable resource for human activities, that almost no human need can be satisfied without energy services, but also that climate change will affect territorial distribution of water resources and, therefore, of the economic activities which depend on it, namely agriculture, industry and energy production, the challenge is to provide energy services with the lower environmental impacts and GHGs emissions. Moreover, the energy sector has, itself, an important potential to mitigate climate change impacts as it can actively contribute to reduce emissions and then smooth climate change impacts. Such potential comes from improved efficiency and from renewable energy potential.

Due to the magnitude of its impacts, climate change has been widely studied by several disciplines. Focusing on the economic analyses, many studies are being carried out but few specifically concentrate on the energy sector, leaving open an important field of research if one considers both its contribution to climate change and its potential to mitigate it.

In what concerns the research method, the economic impacts of environmental-related issues, in particular climate change, may be analysed and assessed under an integrated framework of analysis that simultaneously consider economic and natural (climatic, biophysical, etc.) principles and parameters. Otherwise, only driven by an economic reasoning, the analysis would be too reductive and probably produce misleading results (Politt *et al*., 2010). Thus, the most common and apropriate alternative are the IAMs, which combine economic and environmental/climatic modules that interact and produce feedbacks to each other. Although some caveats remain regarding IAMs (e.g. Hall & Behl, 2006), they continue to appear as the most adequate approach to study such an issue as climate change, especially if further improvements such as those identified in Pollitt *et al*., 2010, are considered.

So, given the magnitude of climate change impacts and their economic effects; the role of the energy sector both as a driver of climate change and as a crucial tool of mitigation, namely through the renewable energies; the lack of studies of the economic impacts of climate change on the Portuguese economy; and the national's potential to renewable energy production (hydropower in particular), we propose to analyse the economic impacts of climate change on the energy sector in Portugal focusing, in particular, on the renewable energy potential to mitigate climate change and to promote sustainable development, using an integrated approach which is expected to provide a comprehensive understanding of the impacts and feedbacks between climate change, the energy sector and the economic performance and social welfare.

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