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Environmental, economic, and social impacts of feed-in tariffs: A Portuguese perspective 2000–2010

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HIGHLIGHTS

- A novel, hybrid input–output analysis of historic feed-in tariff impacts.
- We explore operational, investment, and opportunity cost/benefits in Portugal.
- Environmental (GHG), economic (GDP), and social (job years) impacts are estimated.
- For 2000–2010 we find impacts of −7.2 $MtCO_2eq$ GHG, +1557 M€ GDP and +160,000 job years.
- Lifetime impacts are dependent on opportunity costs of future FIT payments.

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ABSTRACT

Over the past two decades, many countries have used aggressive policies such as feed-in tariffs and power purchase agreements to promote renewable energy. These policies have been very successful in several countries, initiating large changes in the structure of energy sectors, and conferring large environmental, economic, and social impacts. In this paper, we quantify these impacts over the period 2000–2010 for Portugal; a country that witnessed a substantial increase in renewable energy penetration rates, with the share of wind power in electricity production jumping from 0.4% in 2000 to 16.8% in 2010. We use a novel, hybrid energy-economic input–output model to compare the historical energy policy against a counterfactual scenario in which the surge in energy subsidies and concurrent expansion of renewable energies did not take place. We consider the impact of renewable energy policy stemming from three propagation modes – operational, investment, and opportunity costs – in both the energy sector and the rest of the economy. This is the first time such a comprehensive analysis has been undertaken. Our findings show that, in the period under consideration, the combined historical renewable energy policy and renewable energy developments yielded a clear reduction in emissions, in excess of 7.2 $MtCO_2eq$, an increase in GDP of 1557 M€, and a creation of 160 thousand job-years. These estimates do not include opportunity costs from future FIT payments that projects built in this period may be entitled to. Therefore, this work will be of critical interest to RES-E and climate change policy makers, other scientists, and the public.

1. Introduction

Energy produced from renewable sources (RES-E) is becoming a significant fraction of the electricity supply mix in many countries [1]. This expansion has been driven mainly by commitments to national and international targets towards the reduction of greenhouse gas emissions [2], although subsidiary goals such as supply diversification and energy independence also play a role [3]. The rapid expansion of renewable energy has been driven by the implementation of various policy mechanisms [4–7], of which the most prominent are feed-in tariffs (FITs) [8]. In a FIT scheme, a fixed amount of money per unit of renewable electricity is paid to the renewable energy producer, irrespective of market value. The tariff acts as an incentive in compensating for the higher costs of RES-E compared to conventional energy production and its value takes into account the source, environmental aspects, and the inflation

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rate. Tariffs are generally fixed for a long period (typically 15 years to offer long term stability to electricity producers).

Given that FITs are the most prominent policy mechanism for the expansion of RES-E, it is vital that their broad impacts are understood. Herein we split these impacts by environmental, economic, and social indicators; GHG (GreenHouse Gases), GDP (Gross Domestic Product), and JY (Job Years, respectively. The contribution of FIT policies for the reduction of GHGs is generally unambiguous [9–12] but there is research to suggest that some level of infrastructure would be built anyway [13] and that, for some types of generation, the timing of the policy influences the sustainability of developments [14]. The impact of FIT policies on GDP are likely to be large [15], but are not yet as clear as those for GHGs, and vary by the type of analytical approaches used. In a Greek study that combined historical data and a forecast scenario for 2010–2020, Markaki et al. [16] suggested that the capital investment on renewable energy technology has positive impacts on GDP, however operational and opportunity costs/benefits were not explored. Antonelli and Desideri [17] investigated the relationship between FITs and PV cost in Italy, finding that the costs of PV plants are not driven by the amount of installed power but by the tariffs, implying a market distortion which may mean higher opportunity costs. In Wand and Leuthold [18], the potential effects of Germany's FIT policies on roof-top PV between 2009–2030 were explored using a partial equilibrium model in which broad net social costs/benefits were found from −2014 to +7586 M€. By including a merit-order effect, Gallego-Castillo and Victoria [19] found that there are FIT policy settings which give no opportunity cost (for wind power and PV only). Finally, in terms of employment impacts, Lehr et al. [20] studied the impact of the German renewable energy policy on employment using an econometric input–output (IO) model and found that, in the most plausible scenario, the effect is positive. Markaki et al. [16] found that the capital investment on renewable energy technology also has positive impacts on job creation. In the Portuguese case, Oliveira et al. [21] suggested that official goals for RES-E job creation are overestimated. Additionally, several computable general equilibrium (CGE) studies have concluded that current renewable energy policy has a net positive effect in job creation [22,23]. Conversely, in the case of Canada and using a CGE model, Böhringer et al. [24] concluded that policies designed to promote renewable energy have negative impacts on employment. Negative impacts on job creation have been also found by Alvarez et al. [25], whose methodology has in turn been contested by Lantz and Tegen [26]. Lambert and Silva [9] presents additional references on the nexus of employment and renewable energy policy, and concludes that the result of the analysis depends crucially on the spatial scale considered.

We are interested not only in examining the impacts of renewable energy policy within the energy sector itself, but also its implications for the wider economy, through three propagation modes: operational, capital, and opportunity costs/benefits. The operational mode is usually considered in IO studies, and manifests through purchase of the intermediate inputs from the rest of the economy that are necessary for energy production. As renewable energy production requires extensive infrastructure, we also look at the capital formation mode [27]. Finally, because by nature FITs are financial incentives, we also examine the opportunity mode of propagation, which are costs incurred by energy consumers and taxpayers.

To the best of our knowledge, the current literature on quantitative FIT policy impacts is forward looking, using a model calibrated in a reference year and examining the impact of future development scenarios. We are unaware of studies that retrospectively look at the broad impact of historical renewable energy policy. Additionally, prior studies referenced above have focused on one facet of FIT impacts, such as a single propagation mode (capital costs/benefits) or a single RES-E technology (PV). In this study, we offer a contribution to close this knowledge gap in three main ways: firstly, by analysing historic data, we suggest that the impacts computed herein represent an increase in robustness for the impacts of a FIT policy to date; secondly, since we account for impacts in all three modes of propagation, we provide net impacts of a FIT policy, not just one part of the picture; finally, we present a transparent methodological framework for future backward-looking studies which will help reduce the uncertainty in impacts and aid the development of future FIT policy. Therefore, this work will be of critical interest to RES-E and climate change policy makers, other scientists, and the public.

Portugal witnessed a substantial increase in the penetration rate of RES-E from 30% to 54% in the period under analysis, in parallel with the adoption of generous FITs and other subsidies [28,29], and is thus a prime candidate for this study. Note that although we are focused on a particular country, our results have wider, international, implications for the design and implementation of FITs [13] since, as Couture and Gagnon [8] notes, among the most successful implementations (Germany, Spain, Portugal, and Denmark), the payment levels are operated in very similar ways [30,31], i.e. as close as possible in relation to specific generation costs [32,33]. As such, the in-depth study here is internationally applicable to other nations.

The approach we follow to address the research question is to build and analyse an energy-economic hybrid input–output (IO) model [34]. There is a long tradition dating back to the oil crisis [35–37] in this type of analysis, rejuvenated in more recent years by the interest in climate change studies [38–41]. We combine a disaggregated foreground energy sector compiled from multiple sources in an existing model of the national economy [42–44]. We use historical data, calibrating the energy and economic model in every year, comparing the empirical observations against a counterfactual scenario in which the set of incentives that lead to the observed surge in renewable energy penetration did not take place.

The paper proceeds as follows: Section 2 reviews the Portuguese renewable energy policy in 2000–2010; Section 3 describes the approach and methods and Section 4 describes data sources and processing assumptions; Section 5 presents the results; Section 6 presents the discussion; and to conclude Section 7 offers final remarks.

2. Empirical background

This section presents an overview of the most notable features of renewable energy policy and the evolution of the electricity sector in Portugal in the period 2000–2010. The numbers and figures reported are taken directly from the mentioned references.

The share of electricity produced from renewable sources in Portugal reached more than 50% in 2010, from 30% in 2000 [45]. As illustrated in Fig. 1, this evolution was driven by a steady increase in the share of wind power and other renewable energy sources, with large hydro exhibiting year-on-year fluctuations resulting from variations in rainfall. During this period total electricity output increased from 44 to 54 GW h per year.

As shown in Fig. 2, the installed power capacity of nonrenewable electricity sources remained stable during this period, except for natural gas, whose installed capacity reached that of the leader, large hydro. By contrast, the installed capacity of all renewables increased during this period. The installed capacity remained small for all RES-E except wind power and large hydro (below 600 MW), led by combined heat and power (CHP) biomass and small hydro. Wind power, however, exhibited an explosive increase, reaching

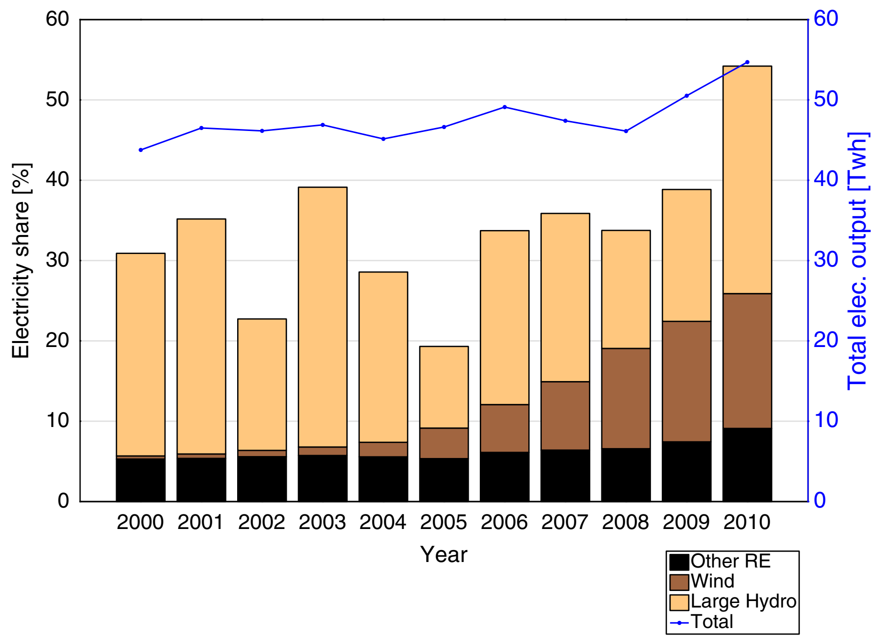

Fig. 1. Evolution of the share of different renewable energy sources for electricity production (RES-E) in Portugal.

an installed power capacity in the vicinity of 4 GW by 2010, on par with natural gas and large hydro (5.2 GW).

The main policy instrument used in Portugal to promote electricity from renewable sources are feed-in tariffs or FITs [28]. Under the Portuguese energy policy, FITs were offered to renewable sources (except large hydro) as well as micro distributed generation (e.g. solar PV, wind), waste and co-generation, and CHP generation from renewable and non-renewable sources. Special incentives and guaranteed purchase prices have been granted to CHP and waste since 1988 [28]. There are also subsidies to electricity production from conventional non-renewable thermal sources (mainly oil, coal and natural gas), Power Purchase Agreements or PPAs, designed to guarantee a pre-established return on investment over the economic lifetime of the plant [28]. Their goal is to guarantee enough installed capacity of a backup technology that can compensate the natural variability of renewable sources.

Fig. 3 shows the historical evolution of these financial incentives, based on data from Amorim et al. [28]. The highest FIT is for photovoltaic, which started at over 500 €/MW h in 2003, and later decreased to 300 €/MW h. Most of the other FITs have steadily increased and stabilized at between 80 and 120 €/MW h.

The combined rise in installed capacity and energy subsidies contributed to a rise in energy costs. The average price of low voltage electricity (usually 230 V) rose from 110 to 150 €/MW h, of medium voltage (10 kV to 30 kV) from 65 to 95 €/MW h and the high and very high voltage (60 kV or higher) from 45 to 60 €/MW h [46]. Hence, prices rose approximately by 50% over this period. The energy bill can be decomposed in several components

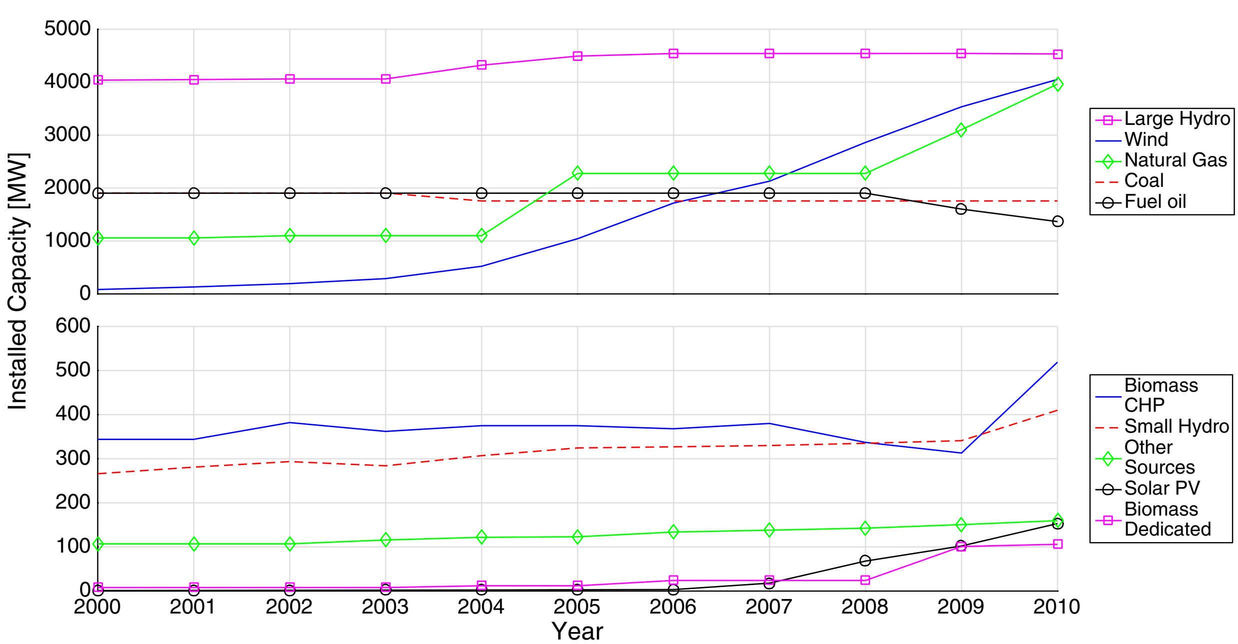

Fig. 2. Evolution of the installed, nameplate power capacity of different technologies, split by size.

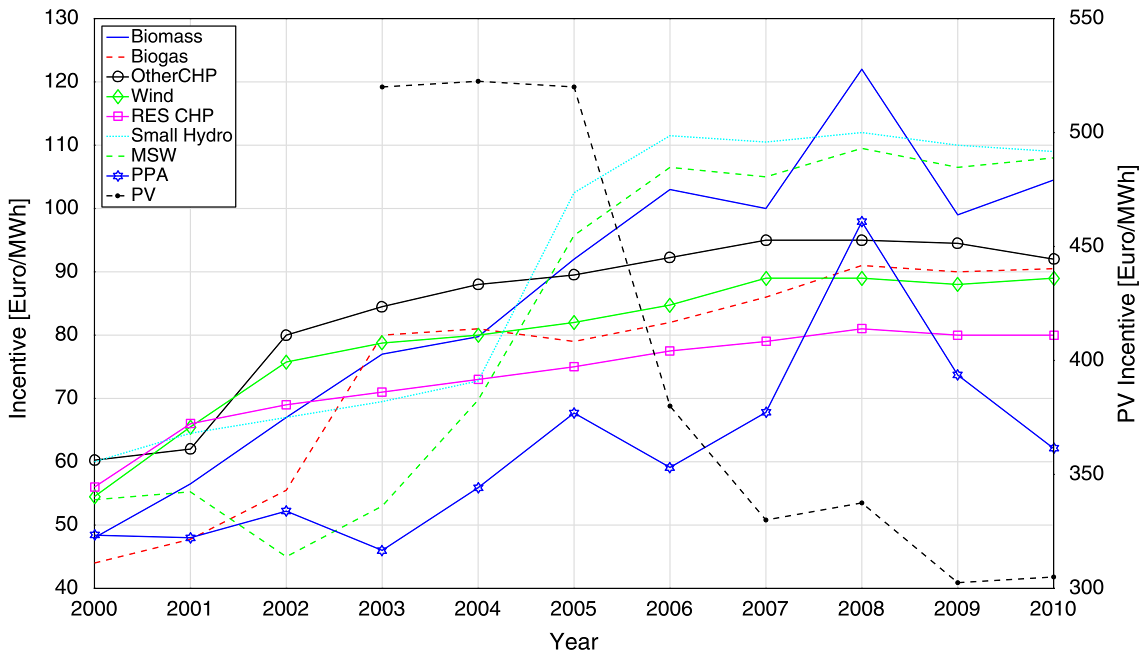

Fig. 3. Evolution of financial incentives (FITs and PPA). MSW stands for municipal solid waste. Secondary axis (right) is only for solar technology.

besides the energy itself, including the grid and general interest costs. The fraction of the energy bill that is used to finance the FITs is close to 8% for low voltage brackets and for the PPAs varies from 4% to 8% [47].

Still, the observed increase in energy costs for consumers was not enough to compensate the rise in energy production costs during this period, which resulted from the expansion of subsidies and from increasing fossil fuel prices [48]. The gap between energy costs and the electricity bill was footed by the government, which accumulated what is known as energy tariff deficit [28] to be paid with interest over a period of more than a decade. In the period under analysis, the gap between total costs and consumer bill changed from 1568 $M€_{2002}$ in 2000 to 2125 $M€_{2002}$ in 2010, a figure which includes debt incurred to finance both FITs and PPAs among other items [49].

3. Methods

In Section 2 we observed that during the period under analysis there were substantial shifts in the share of sources in total electricity output and installed capacity, as well as in the financial incentives that support them. Our goal in this paper is to quantify the environmental and socio-economic impacts of those changes. The variables we will examine are the impacts on GreenHouse Gas emissions (or GHG, measured in $MtCO_2eq$), Gross Domestic Product (or GDP, measured in M€) and Job Years (or JY, measured in thousand years, ky).

We quantify those impacts both in the energy sector itself and in the rest of the economy. The energy sector is the set of different technologies for production (coal, gas, wind, hydro, etc.), transmission and distribution of electricity and fossil fuels. The rest of the economy are agriculture, manufacture and services, further subdivided into other subsectors.

We will distinguish direct and indirect impacts. Direct impacts can only occur in the energy sector itself and are those directly associated with renewable energy policy, for example if a worker is hired in the wind power sector, or if GHG emissions drop because a gas power station is turned off, as a consequence of the FITs. Indirect impacts can occur both in the energy sector and in the rest of the economy are those impacts which propagate along the supply chain of goods and services, for example an increase in value added generation in the steel industry due to increased demand to supply the construction of a new wind farm.

Total (direct and indirect) impacts of a demand stimulus $\Delta\mathbf{y}$ on some environmental or socio-economic intervention (e.g., GHG emission, GDP, or employment) Δr are calculated using the Leontief model [50], which reads:

$$\Delta r = \mathbf{b}'(\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{y}, \quad (1)$$

where bold denotes a matrix object, uppercase denotes a matrix and lowercase denotes a vector. In the remainder of this paper vectors are in column format by default, ′ denotes transpose and italic denotes a scalar.

Object $\mathbf{b}$ is the vector of intervention coefficients and $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse or total requirement matrix. $\mathbf{A}$ is the matrix of technical coefficients and A_{ij} expresses the purchases of i that are required to generate one unit of output of j. Direct coefficient b_i expresses the amount of intervention that occurs per unit of total output of industry i. Total requirement L_{ij} expresses the total output of industry i that is stimulated by a unit demand for product j.

In the conventional Leontief model $\Delta\mathbf{y}$, the change in final demand is the (exogenous) control variable, $\mathbf{A}$ and $\mathbf{b}$ are parameters and Δr is the (endogenous) return variable. According to the System of National Accounts [42], final demand is broken down into consumption by institutional sectors, mainly households and government, fixed capital formation and exports, besides smaller components. Households are families and individuals, and their component of final demand is what is commonly understood as private consumption. Fixed capital formation or investment is the accumulation of durable goods such as buildings, machines or transport equipment (also including intangibles such as computer software).

In this paper however, we are not interested in calculating the impact of a final demand stimulus but rather the impact of a historically observed renewable energy policy. We do so by contrasting the reference scenario (the observed evolution of energy consumption) against an alternative scenario which describes a counterfactual evolution of the renewable energy sector. We make the following assumptions:

- In the alternative scenario the observed expansion in the share of renewable energy in electricity production does not take place, being replaced by natural gas.
- In the alternative scenario the observed expansion in the installed capacity of renewable energy infrastructure does not take place.
- In the alternative scenario no financial incentives to support renewable energy are passed on to consumers and taxpayers.
- Final demand in the economy for energy services and for commodities from the rest of economy is the same in both scenarios.

The counterfactual energy policy against which we compare has the same observed changes in the final demand for energy services as over the 2000–2010 period. This implies that in the counterfactual, the energy needs of the country were still met, but that they were met with non-renewable generation. We make the assumption that these needs were met by increasing the load factor of natural gas generation in the system. This assumption is plausible as natural gas is already the backstop technology for shortages, and because it is the least intensive energy source in the energy portfolio (which does not contemplate nuclear and has commitments under Kyoto). It is important to note that the counterfactual does not take into account increases in RES-E that would have occurred in the absence of FIT policy. As such the estimates here should be thought of as a maximum-cost estimate of the impacts of combined policy and autonomous RES-E developments, as further discussed in Section 6.

Formally, we model the net impact of renewable energy policy as the sum of the impacts across three separate modes of propagation, operational costs, capital formation and opportunity costs:

$$\Delta r_T = \Delta r_O + \Delta r_K + \Delta r_S, \tag{2}$$

where Δr is the difference in environmental, economic, or employment impacts between the reference and counterfactual scenarios for a particular dimension of interest (GHG, GDP, or JY). Subscript T refers to total impacts. Subscripts O, K and S refer impacts in the operational, capital and opportunity modes of propagation, respectively.

Operational costs are the expenditure of firms for the purchase of goods and services necessary for production (of electricity, in this case). Within this mode of propagation we therefore subsume the direct impacts occurring in the energy sector due to energy production and the indirect impacts in the rest of the economy due to purchases related to energy production.

We use the theoretical framework developed by Rodrigues et al. [51] for waste management policies to model the operational mode of propagation here. In contrast to the conventional Leontief model we consider final demand, $\mathbf{y}$, as a parameter that is fixed (i.e., common for both the reference and counterfactual scenarios) and instead treat the technical coefficients as control variables. We apply the Leontief model using two different technical coefficient matrices: the empirically observed one, $\mathbf{A}$, and a hypothetical counterfactual, $\mathbf{A}^{\text{Alt}}$. Operational impacts, Δr_O, are calculated using Eq. (3):

$$\Delta r_O = \mathbf{b}'\left((\mathbf{I}-\mathbf{A})^{-1} - \left(\mathbf{I}-\mathbf{A}^{\text{Alt}}\right)^{-1}\right)\mathbf{y}. \tag{3}$$

The counterfactual technical coefficient matrix, $\mathbf{A}^{\text{Alt}}$, describes the direct requirements that would occur if the observed renewable energy policy had not been implemented. The alternative technology matrix is identical to the reference technology, $\mathbf{A}$, except that all RES-E production is capped at the 2000 level, with the difference to the observed electricity production being supported by natural gas, as described above.

Capital formation or investment costs are incurred when there is an expansion in infrastructure (of electricity production, in this case). The expansion of the electric grid and construction of power generation facilities therefore led to indirect effects, for example employment in the construction sector during the installation of wind turbines.

Capital impacts, Δr_K, are calculated using Eq. (1), with the stimulus vector, $\Delta\mathbf{y}$, being the observed capital formation that can be attributed to RES-E infrastructure, e.g., the expenditure for purchasing and assembling wind turbines, establishing grid connections or other RES-E development.

Capital impacts are allocated to the year in which capital formation occurs using empirically available information, so there is no need to amortise costs or normalise the effect of inflation.

Opportunity costs emerge because FITs represent a net subsidy to electricity producers which is incurred by energy users and tax payers. Hence, in the counterfactual scenario, by not subsidising FITs, the budget of households and firms would expand and there would be an expansion of their expenditure, leading to indirect impacts. For example, if households had a smaller electricity bill they would have more money available to travel more.

Opportunity impacts, Δr_S, are also calculated using Eq. (1), but now the stimulus vector is the reduced consumption due to FIT payments. We assume that the consumption profile (i.e., the share of expenditure in a particular item) is identical in both the reference and alternative scenarios, but this profile changes from year to year according to the empirical observations. Notice that the costs of subsidising the FIT are shared among all electricity consumers, including both households and firms.

A complicating factor in the accounting of opportunity impacts is the existence of the tariff deficit, described at the end of Section 2. Since this tariff deficit will run into the period beyond 2010, 2011 onwards is in the future from the perspective of our scenario generation. We addressed this problem by separately accounting for the opportunity costs that accrue from 2011 onwards due to payment amortisation and interest payments. We assume that the tariff deficit is repaid like a loan, i.e. repaid in equal, annual instalments over a set period, and with a set interest rate. The opportunity cost in each year is the sum of the present value of the deficit loan and the amount that was actually repaid in that year. We calculate the net present value using Eq. (4).

$$V_p = \frac{rND}{1-(1-r)^{-N}} \tag{4}$$

where V_p is the present value of a deficit D, paid in equal annual instalments, amortised over N years and at an interest rate of r. However, since the tariff deficit repayments will be made in an unknown future (from 2011 onwards), we are unable to directly model the opportunity costs of the repayments under unknown economy assumptions. To gain an understanding of the uncertainty, we keep the total future amortization and interest payments fixed but use different technology bundles. For example, for the opportunity impacts in 2005, we take the full amortized repayments and interest for 2005 and calculate the impacts using Eq. (1) for the technology assumption in each year through the period 2000 to 2010. This results in 10 different estimates of opportunity impacts. The maximum and minimum impacts are then the error bounds on the estimate.

4. Data and assumptions

The reference technical and intervention coefficients $\mathbf{A}$ and $\mathbf{b}$ were calibrated from source flow data as:

$$\mathbf{A} = \mathbf{Z}\,\mathrm{diag}(\mathbf{x})^{-1};$$
$$\mathbf{b}' = \mathbf{r}'\ \mathrm{diag}(\mathbf{x})^{-1},$$

where diag represents diagonal matrix, and the flow data satisfies the accounting identity:

$$\mathbf{Zi} + \mathbf{Yi} = \mathbf{x}; \tag{5}$$

where $\mathbf{i}$ is a vector of ones, $\mathbf{Z}$ is the matrix of inter-industry flows, $\mathbf{Y}$ is the matrix of final demand flows and $\mathbf{x}$ is total output.

As mentioned in Section 3, we are interested in identifying impacts in both the energy sector itself and the rest of the economy. We therefore elaborate the energy-economic hybrid described in Guevara and Rodrigues [52], which reports time-series data from 1995 to 2010. The model of Guevara and Rodrigues [52] has three main components:

- The use of primary energy carriers within the energy sector and their transformation into final energy carriers to be used by the rest of the economy, in energy units. The energy sector is characterised by 18 energy technologies (wind, gas, hydro, etc., including transmission and distribution) and 42 energy carriers. The main data source are the annual national energy budget provided by DGEG (Directorate General-Energy and Geology, http://www.dgeg.pt).
- The use of final energy carriers by the rest of the economy (intermediate and final consumers), in energy units. The main data source for this is the use of carriers by different economic sectors, provided by INE, (National Statistics Institute, National Accounts, http://www.ine.pt). The alignment between energy and economic data involved aggregation as well as disaggregation, in accordance with the official classification of economic activities [53].
- The use of products by industries to generate new products and their use by final consumers, in monetary units. The rest of the economy (i.e., outside the energy sector) is described by 49 industries and 49 product categories based on the NACE 2-digit classification, and all monetary data reported in constant prices of 2002 (i.e., values in other years were deflated to take into account inflation). The main sources here were the harmonised supply and use tables provided by Eurostat (http://ec.europa.eu/eurostat).

For the goals of the present study additional information had to be collected, as described below. For consistency, all additional monetary data was deflated to constant prices of 2002 too. Note that different data components might have been reported in different classifications and had therefore to be aggregated or disaggregated to match the model described above. The time frame of analysis, 2000–2010, was chosen as a compromise between data availability and the existence of a clearly observable energy transition, illustrated in Section 2.

Information about GHG emissions (CO_2, CH_4 and N_2O) in the rest of the economy were obtained from Eurostat, with the global warming potential conversion factors to CO_2-equivalent obtained from Forster et al. [54]. Concerning the energy sector proper we gathered the following information: installed capacity power, investment and operational costs, GHG emissions, employment, financial incentives and decomposition of the energy bill.

The installed power capacity was gathered from information presented in DGEG [55], INEGI [56], Ferreira et al. [57] and Holm et al. [58]. Operational, maintenance and investment costs of different energy technologies were obtained from EU [59], Kaplan [60], EIA [61], NREL [62] and IEA [63]. GHG emission factors were obtained from the IPCC 2006 Guidelines [64] and the global warming potentials from Forster et al. [54]. Employment data was obtained from Rutovitz and Harris [65]. Data on subsidies to electricity producers data were obtained from Amorim et al. [28] and the discrimination of financing by households and activities was performed using data from ERSE [47]. The use of products from the rest of the economy by different energy technologies was characterised with data provided by Oliveira et al. [21].

The breakdown of investment costs within each energy technology was collected from multiple sources: Krohn et al. [66] for wind energy technology; IRENA [67] and IEA [68] for hydro power

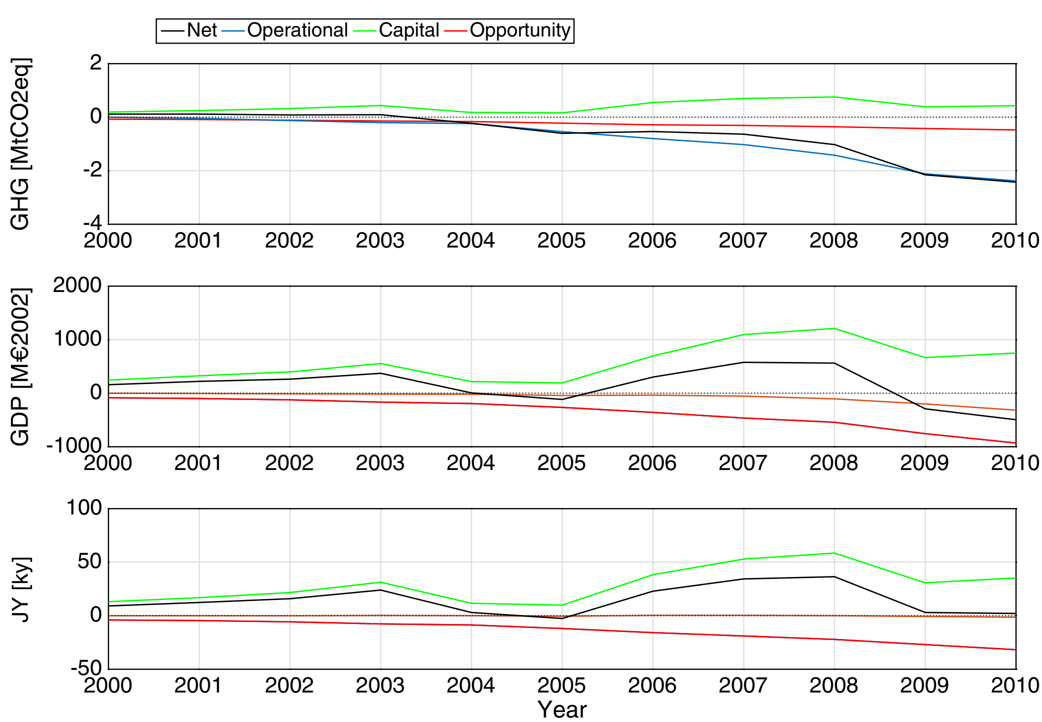

Fig. 4. Summary of RES-E policy impacts over the period 2000–2010 compared to the counterfactual split by operational, capital, and opportunity modes of propagation.

plants; IEA [69] and Henneberger [70] for geothermal power plants; and NREL [62] for the remainder technologies. These process-based production recipes were then matched with the total capital formation of the electricity sector reported in table C.3 of the national accounts, also provided by the INE website.

The impact of the tariff deficit was calculated using an average maturity of 15 years and an interest rate of 3% [49, p. 44]. The tariff deficit in every year was calculated as the difference between production costs and the consumer bill.

These data types are available for many nations, in some cases, the same or similar sources can be used to collect data on other European nations for further in-depth analyses of this type in other nations.

5. Results

This section presents the main results of our analysis, based on the methods described in Section 3, and using the data described in Section 4. The numbers and figures reported are an elaboration of the resulting calculations.

Fig. 4 summarises the impact of renewable energy policy in Portugal on GHG emissions, GDP, and job creation in the period 2000–2010 through three propagation modes (operational, capital, and opportunity).

Initially, all types of impacts were small, reflecting the pick-up in the spread of FITs and RES-E. In time, these impacts rose in magnitude and patterns diverged. In the period under analysis net GHG

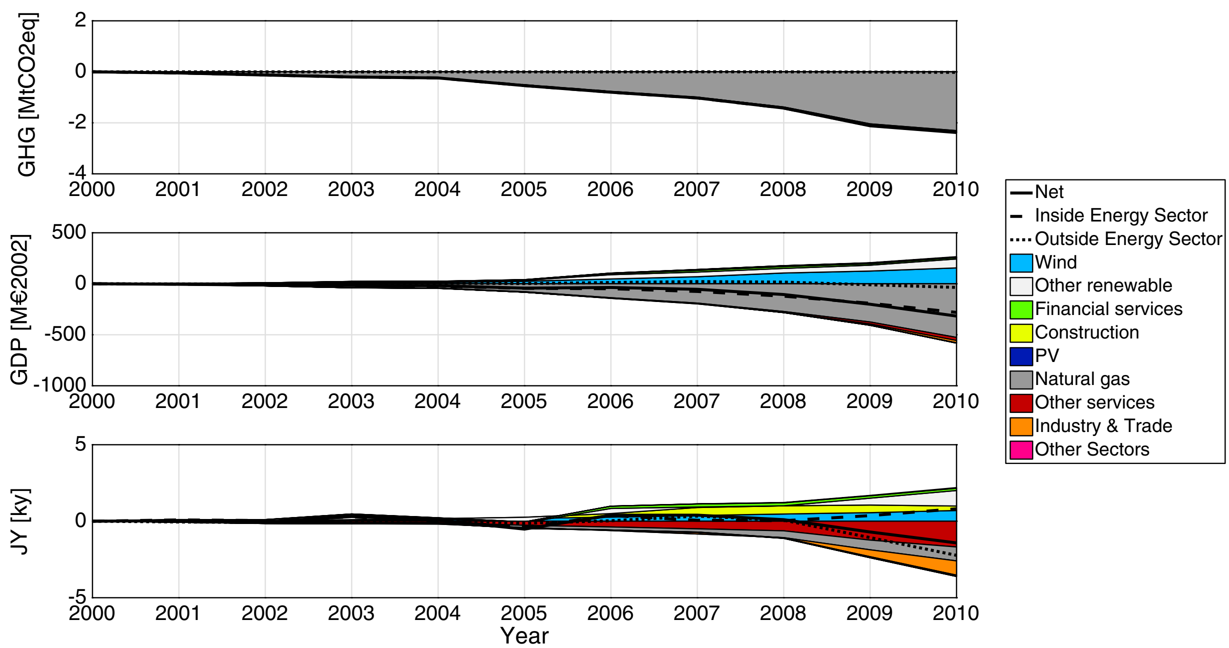

Fig. 5. Operational impacts for energy and economic sectors by GHG emissions, GDP, and JY.

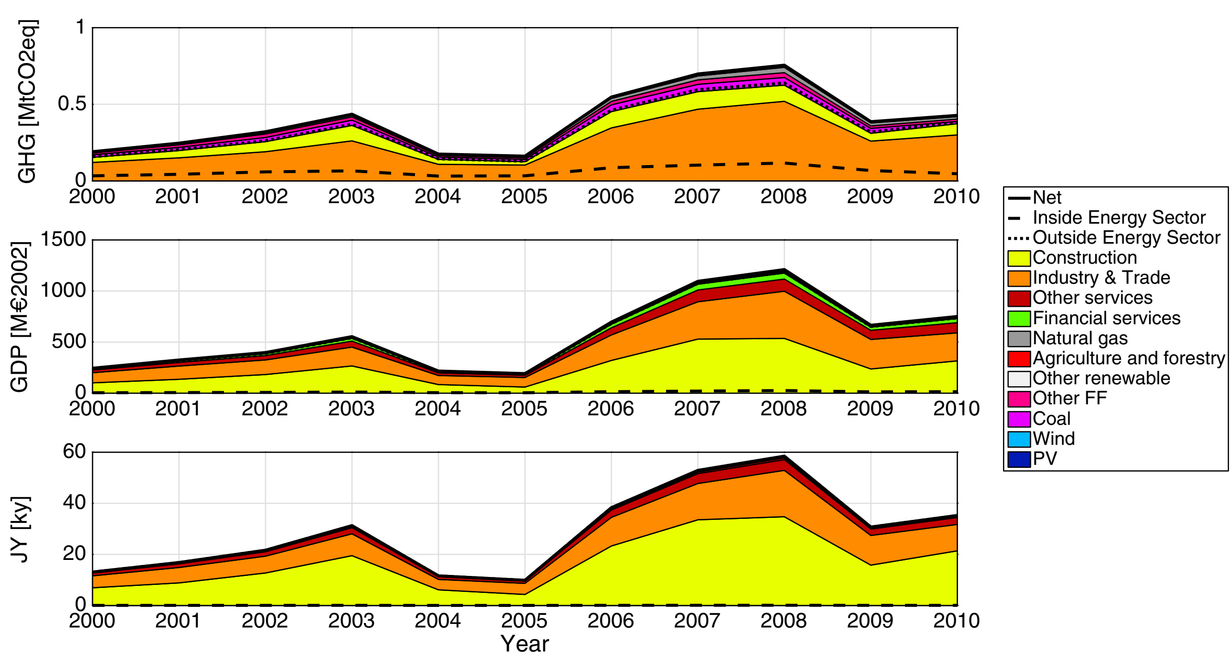

Fig. 6. Capital formation impacts for energy and economic sectors by GHG emissions, GDP, and JY.

emissions exhibited a steady and significant decline, dropping to net yearly savings of 2.4 $MtCO_2eq$. Impacts of the capital mode of propagation are all positive, as these are the impacts associated with the installation of RES-E infrastructure and formation of capital. Cumulative, net GHG impacts, calculated by summing over the 10 year period of analysis, show a mitigation of 7.2 $MtCO_2eq$. By contrast GDP oscillated, reaching a maximum creation of 577 M€ in 2007, and a reduction of 495 M€ in 2010. JY also oscillated, but remained positive for most of the period, resulting in a maximum of 42 ky in 2008 and a reduction of 2 ky in 2005. Cumulative, net impacts for GDP equate to a creation of 1557 M€ and for employment, a creation of 160 ky.

The evolution of the three modes of propagation differed significantly: operational costs have a major role in GHG savings, but minor in GDP and employment; capital formation had a significant and strictly positive impact (i.e., increase) across all propagation modes; by contrast, opportunity costs had a strictly negative impact (i.e., savings) across all propagation modes. Overall, opportunity costs became key determinants of global GDP and employment impacts by the end of the period under analysis.

Two key shifts in the capital impacts can be seen, once in 2003, and again in 2008. The shift in 2003 reflects the construction of a large municipal solid waste plant and a peak year in wind development in the early part of the decade. The shift in 2008 is dominated by the peak development of wind and photovoltaics during the decade. The subsequent reduction in the expansion of the RES-E infrastructure after 2008 can be explained by the global recession and national financial crisis, which led to a sharp increase in the cost of capital and a general climate of uncertainty that discouraged investment.

It is interesting to put these figures in perspective, by examining the impacts as a percentage of the total energy sector and total national values. In the final year of analysis, 2010, mitigated emissions comprised 19% of the total GHG emissions of the energy sector and 4% of total national emissions; GDP showed a 8.3% decrease within the energy sector, and a reduction of 0.3% of the whole economy; and job creation showed an increase of 6% in the energy sector and 0.04% increase in the national labour market.

Disaggregating these impacts into the sectors in which they occur gives further insight into how the structure of the economy changes in response to RES-E incentives. In particular, we want to distinguish whether they occur within the energy sector itself or in other economic activities. Fig. 5 splits the overall impacts for the operational mode of propagation into energy technologies and aggregated economic sectors.

For both GHG emissions and GDP creation, the majority of impacts are felt within the energy sector itself, with residual, small impacts in the rest of the economy. We see the largest reduction in GHG emissions within the energy sector itself, as may be expected. This is as a result of the emissions avoided in just one sector, natural gas, since it was assumed that this would have replaced the RES-E in the counterfactual scenario. The reduction of GDP due to the operational factors is related almost entirely to the reduction of the natural gas sector, and while some of this is counterbalanced by the wind sector, there is a net reduction of 200 M€ by 2010.

The impact of the operational mode of propagation on employment, while small, has repercussions both inside and outside the energy sector. The largest positive impact on JY include construction, wind, and financial services. Notice that the operational and maintenance costs (as opposed to capital formation) persist for as long as an equipment is in use and that energy infrastructure has a life expectancy of several decades. This implies that while these impacts are small they would be expected to continue past the time frame of this study, as they are related to the structural evolution of the energy sector.

Fig. 6 splits the capital mode of propagation in the same way. The capital mode of propagation can be thought of as the impacts associated with infrastructure, so will necessarily be positive in all impacts (in the mathematical sense, not in the sense of being beneficial) as in the counterfactual there was sufficient natural gas capacity so that no further infrastructure development was necessary. The construction and industry & trade sectors see the largest sector impacts. Industry & trade comprises the largest growth in GHG emissions, with construction the second largest. Some smaller changes in emissions are seen in coal and natural gas, which are related to the fabrication of the renewable energy units. For impacts

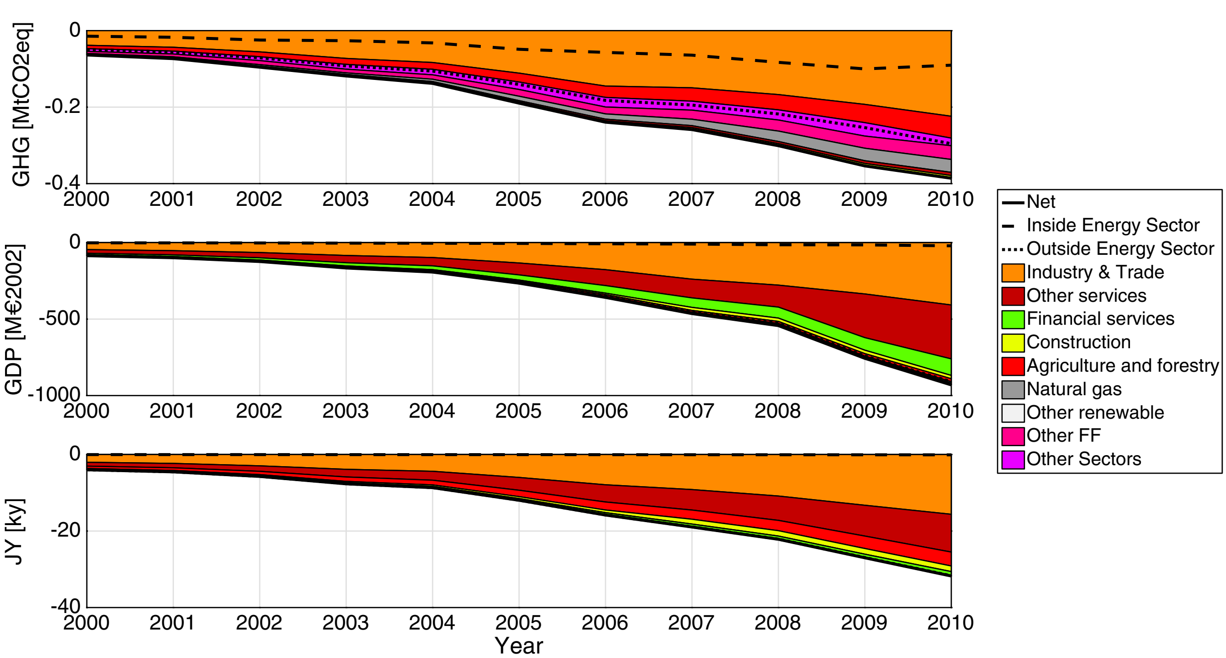

Fig. 7. Opportunity impacts for energy and economic sectors by GHG emissions, GDP and JY.

in employment, these are reversed, with construction providing the largest increase in employment. This is perhaps unsurprising given the labour intensive nature of infrastructure development. Finally, the increased GDP associated with these capital investments are split equally between industry & trade and construction.

Finally, Fig. 7 shows the sector impacts of the opportunity mode of propagation. As the deficit was built in the payments of the FITs as described in Section 2, these future repayments were included in the 2000–2010 timeframe. As the opportunity costs are a reflection of consumer patterns as described in Section 3, the GHG reductions are twice as large in the rest of the economy than the energy sector. The energy impacts are seen largely in natural gas as the opportunity cost of the FITs would suppress consumption of electricity (which was assumed to be back-filled with natural gas). The largest sector across all impacts is industry & trade as might be expected with a reduction in consumption. It is important to highlight that although levels of FIT vary with time (see Fig. 3) the payments are usually guaranteed for 15 years.

6. Discussion

This study characterised the economy-wide impacts of RES-E and FIT policy, by comparing historical data against a counterfactual under which renewable energy development would not have occurred. We assume that the observed RES-E developments would have not been economical or built without the FIT. Since there may have been some percentage of RES-E infrastructure that might have been built regardless of the presence of a FIT (for example wind production at the best sites), the estimates presented here imply a 'maximum cost' estimate. While we are unable to estimate the proportion of RES-E that would have been built anyway, it is important to note that the role of FITs as a key driver of RES-E infrastructure is generally uncontroversial [8,17,12]. These estimates were further split by mode of propagation: capital formation (building new infrastructure), operational (running the equipment) and opportunity (the loss of income incurred to subsidise the FITs).

An important caveat to our results is that the longevity of impacts will be dependent on the mode of propagation. While we find cumulative net impacts of a GHG reduction of 7.2 $MtCO_2$-eq, a creation of 1557 M€ in GDP, and a creation of 160 ky in JY, we expect operational impacts to continue for the lifetime of the infrastructure (generally considered to be 25 years, but which in practice may be even longer). Conversely, the impacts of capital formation are short-lived because only minor additional investment is necessary during the lifetime of the infrastructure. The situation with opportunity costs is intermediate, since producers are entitled to continuing FIT subsidies for a period of 15 years, without guarantee of additional subsidies thereafter.

We can use these estimates of the various time frames to harmonise the impacts resulting from the different modes of propagation, to provide a lifetime estimate for the total impact of the FIT policy in the period 2000–2010, including the propagation of opportunity costs into the future. The operational component was modelled by assuming that the impacts of the most recent year propagate for a period of 25 years. Impacts from investment were assumed to be confined to the 2000–2010 decade. Finally, opportunity costs were assumed to continue at the 2010 level for 3 years and then to wind down to zero during the following decade. In keeping with a 'maximum cost' philosophy, we assume no discount rate in the opportunity cost.

Combining this information we find a total mitigation of 71 $MtCO_2$eq resulting from the energy policy implemented in the period 2000–2010. This implies that the fraction of emissions mitigation that result from the policy and actually occur during the time frame 2000–2010 was just 10%, with the remainder occurring after 2010. Similar figures for GDP are a total reduction of 13 thousand M€, implying that only 11% of the impacts occur within the original time frame. Finally, for job creation the total impacts of the policy are a reduction of 128 ky, meaning that 56% of the impacts occur within the original time frame. Thus, we see that for GHG emissions and GDP creation, impacts extend deep into the future while roughly half of the effects on employment occur within the period of implementation of the policy. These figures are back-of-the-envelope calculations intended to provide an insight about the importance of the time span implications of a policy in a historical analysis, and they depend critically on the FIT life span considered and energy market prices.

It is interesting to note that the interest repayments incurred by the decision to run a tariff deficit confers non-negligible impacts. The impacts of opportunity costs increased by an order of magnitude from 2000–2010, but most still occur in the future, spread over the time horizon of 15 years in which the tariff deficit is being recovered. Instead, if the Portuguese government had made the decision to pay the FITs upfront, the total impacts described above (i.e., also including impacts occurring after 2010) reduce to 69 $MtCO_2$eq mitigated, reduction of 10.5 thousand M€, and reduction of 38 ky.

The calculations described in the preceding paragraph were performed by removing the opportunity costs associated with interest payments and considering that remainder opportunity costs are passed fully to electricity consumers in the same year in which the FIT is paid to electricity producers. This observation highlights the importance of opportunity costs to the total impact of a renewable energy policy, not only in terms of the size of the FIT subsidy, but also whether its cost is passed on to current or future generations. These results are of interest to international policy makers when designing such policies.

Other factors that may impact these estimates will be future changes in carbon price, and other policies for the control of GHG emissions. Any policy implementation moving to increase the cost of GHG emission will only soften opportunity impacts into the future. Finally, notice that there are ancillary benefits such as the pricing of risk due to increased energy security, the increase in air quality, and the reduction of pollution costs, which are not being taken into account here, again highlighting the fact that this is a maximum cost estimate of the FIT policy during this time period.

It is also important to acknowledge that the uncertainty of our results differ across modes of propagation, with impacts resulting from operational and capital costs being more accurate than opportunity costs. The latter have a distributional aspect which was not covered in this study, but which undoubtedly merits more attention in the future. In order to capture at least some of the uncertainty, we performed a sensitivity analysis to examine how the results were affected by the expenditure profile of consumers. Thus, for every year under analysis, we considered the same total expenditure by taxpayers and consumers of electricity to support the FITs, but besides the observed expenditure profile in that year we also calculated the impacts of the expenditure profile of every other year in the period under study. Our results showed that the sensitivity to the expenditure profile was capped at 0.24 $MtCO_2$eq, 6.4 ky, and 71 M€. Ideally, though, opportunity costs would be captured with more detail by splitting households into different income categories and using a different consumption profile for each income category.

When comparing our results for employment with those in the literature, a commonly reported job indicator is the job ratio, calculated here by dividing the Job Years created or destroyed per MW RES-E installed by the assumed lifetime of the system, in this case 25 years [9]. We find a job ratio over the 2000–2010 period of 1.15 jobs/MW. This estimate is of a similar order of magnitude as found in other studies: for example Blanco and Rodrigues [71] found job ratios of wind in Spain of 1.35 jobs/MW and Lambert and Silva [9] report job ratios varying from 0.76 to 6.97 in various EU countries. In terms of employment generation by RES-E energy provided, rather than installed capacity, we find a ratio of 0.27 jobs/GW h, which agrees well with averages between 0.08 and 0.32 for wind and biomass as reported in a review of European and U.S. studies by Kammen et al. [72], summarised in Lambert and Silva [9].

7. Conclusions

There are few studies of full policy impacts of FITs due to the difficulty of examining economy wide impacts [13]. Here we provide, to our knowledge, the first examination of the economy wide impacts of historical costs and benefits of renewable energy policy. We split impacts by their mode of propagation through the energy sector and the rest of the economy: operational, capital, and opportunity.

Our main results, elaborated in Section 5 indicate that the historical renewable energy policy in Portugal 2000–2010 led to cumulative net impacts of a GHG reduction of 7.2 $MtCO_2eq$, a creation of 1557 M€ in GDP, and a creation of 160 ky in JY. In order to allow for international comparisons, we put these figures into perspective by dividing cumulative impacts over the accumulated emissions, GDP, and employment in the period 2000–2010. We find that the combined energy policy and RES-E infrastructure over 2000–2010 led to significant GHG emission reductions (1% of national emissions), while impacts on JY were an order of magnitude lower (+0.2%) and the impact on GDP was negligible (less than −0.001%). In the final year of analysis our results show a significant GHG emission reduction (4% of national emissions), while impacts on GDP and JY were again orders of magnitude lower (−0.3 and +0.04% of national totals, respectively).

Furthermore, in Section 6 we further extend the discussion and provide tentative estimates of the consequences of the renewable energy policy beyond the period 2000–2010. We argue that due to technological lock-in, and the fact that GHG emissions were affected mainly by the operational mode of propagation, a significant part of GHG savings (90%) are likely to occur in the future (i.e., beyond 2011). GDP was mainly affected by opportunity costs, therefore a large fraction of GDP reduction (89%) would also occur in the future. Initially, employment was driven by capital formation but later, as construction of new infrastructure abates, opportunity costs dominate and net impacts become negative. It should be mentioned that the even over this extended time horizon, the relative impact of the renewable energy policy 2000–2010 on GHG emissions is an order of magnitude greater than the relative impact on GDP, which in turn is another order of magnitude greater than the relative impact on employment.

While there are limitations inherent in this approach due to the time window of investigation, by taking a maximum cost approach we can provide an upper limit of these policy impacts. Given the high similarity between the Portuguese FIT settings and several other European nations [8], these results will be of further interest when considering other FIT policies internationally.

As the large scale deployment of RES-E technologies matures it will become possible to replicate this type of backward-looking study with tighter estimation bounds, as the fraction of spillover effects beyond the time horizon of the analysis diminishes. By having a provided a transparent methodology for the assessment of the impacts of FITs across various modes of propagation we provide a template for similar studies in other countries and time frames. We believe that the knowledge thus gained can better inform policy makers and guide the design of RES-E incentives which are both cost-effective and environmentally sound.

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