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Economic analysis of the profitability of existing wind parks in Portugal

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ABSTRACT

Discussions on the appropriate policy design and level of incentive to promote renewable energy adoption and meet the 20/20/20 goals have spurred recently in the European Union. These discussions are also ongoing in Portugal, namely in what concerns the level and duration of feed-in tariffs that should be provided to independent power producers. This, in turn, raises the question of whether the past feed-in tariff levels were well designed to achieve the goals of a larger penetration of renewables in the Portuguese grid. The policies to induce wind adoption have led to a growth in wind installed capacity and share of electricity generated by wind in Portugal, but questions arise on their cost-effectiveness and whether alternative policy designs would have led to the same goal. In this work, we estimate profits made by wind independent power producers for wind parks that were connected in Portugal between 1992 and 2010, and conclude that the feed-in tariffs have overcompensated some wind power producers. We also discuss the recent changes in feed-in tariff legislation published in February 2013 and estimate the expected costs of the introduced changes.

1. Introduction

Global wind power increased by 200 GW in the past five years. Just in 2013, the industry grew by 12.5%, due mostly to an increase in installed capacity in China and in Canada (GWEC 2014). Around the world, several countries so far have or had renewable tariff schemes. However, the design and implementation of such schemes vary substantially across countries both in terms of design and amount (Mendonça, 2007; Mendonça et al., 2009). For example, in Spain, a renewable electricity producer could choose between receiving a fixed price or a bonus on top of the spot electricity market price; in Denmark the tariff would correspond to a bonus on top of the electricity market price; and in Germany the incentive included a fix base tariff to which a bonus could be added (BMU 2011).

Portugal, too, has implemented mechanisms to incentivize the production of electricity from renewable sources. Today, wind accounts roughly for 20% of electricity generation. Wind power has been added to the grid since the late 1980s: since 1988 Portugal has a feed-in tariff (FIT) system, i.e., a guaranteed price for electricity generated from several renewable energy sources (Diário da República, 1988), including wind. The wind FIT scheme in Portugal was applied since the construction of the first wind park in 1992, and as of February 2013, FITs are guaranteed for the first 20 years of production or until the production of the wind park reaches 44 GWh per MW of installed capacity (Diário da República, 2013).

In Portugal, FIT values are defined according to a formula established by legislation. The amount is computed every month by the energy regulator (ERSE) for each independent power producer (IPP) according to several factors, such as inflation, avoided costs and environmental benefits.

The Portuguese wind policies and associated legislation have been changing over time, and so has the formula used to compute the monthly FITs provided to IPPs for wind and for other energy sources, and therefore the level of incentive that independent power producers obtained. Fig. 1 shows the four main laws where FIT formulas changed, as well as the reported average annual national FIT for wind over time.

As shown in Fig. 1, the annual national average FIT for wind ($/MWh) decreased from 1992 to 1999 (all costs and benefits throughout the

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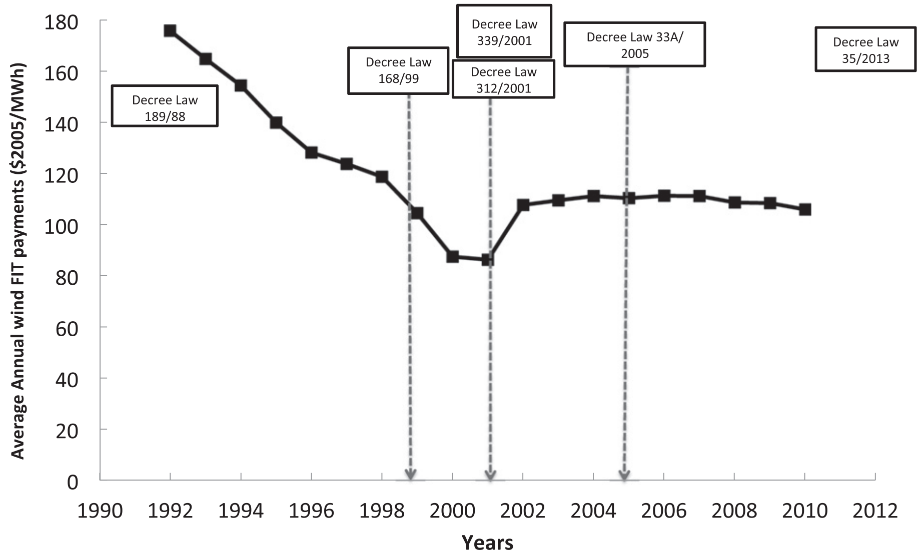

Fig. 1. Average annual wind FIT in Portugal over 1992–2010 ($2005/MWh). Constructed using data from (ERSE, 2011).

paper are in dollars of year 2005. The euro-dollar exchange rate used was 1.24 euro/$ for year 2005). In 1999, FIT values started to include environmental benefits that arise from avoided construction of additional fossil fuel power plants. Since 1999 until today, the FIT formula assumes that the carbon intensity of the Portuguese grid is of 370 g CO_2 per kWh (Diário da República, 1999) and that the externalities associated with CO_2 are valued at $20 per metric ton of CO_2 (Diário da República, 2005).

In 2001, FIT started to differ by technology. Before 2001, a kilowatt-hour generated from solar energy received the same payment as a kilowatt-hour generated from wind energy (Diário da República, 2001). This change led to an increase in wind FIT of approximately 20%.[3] Also in 2001, Decree-Law 312/2001 specified two public procedures for wind power producers to have connection rights: (1) a direct procedure in which parks individually ask for a connection license when the Directorate of Energy (called Direcção Geral de Energia e Geologia, or DGEG, in Portugese) establishes available connection points, and (2) a public tender in which specific criteria apply to grant connection licenses. About 3000 MW was granted up to 2005 under the 'direct procedure' specified in 2001, and 1900 MW was allocated between 2006 and 2008 according to the 'public tender procedure' that opened in 2005. In addition, Decree Law 339/2001 established that wind IPPs would pay 2.5% of the total revenue obtained from power generation to their respective municipality (Diário da República, 2001).

In 2005, the wind FIT was established for either 15 years or until producing 33 GWh per MW of capacity installed (Decree-Law 33A/2005). Oddly enough, the 2005 legislation also provided that all projects connected before 2005 had an additional 15-year period of FIT starting February 2005, regardless of the number of years they had been already operating and under the FIT mechanism. Therefore, according to Decree-Law 33A/2005, only by January 2020 will some wind parks be ending their FIT period.

The decree law in 2005 (33A/2005) established that after a 15-year period where IPPs are provided with a feed-in tariff, wind parks would start receiving the average annual spot electricity market price plus the value of green certificates[4] those green certificates are available. If a green certificates scheme is not available when the FIT period ends, the FIT is to be extended for five additional years. Since 2012, wind IPPs, which are predominantly represented by the Portuguese Renewable Energy Agency (APREN), have been negotiating with the Energy Regulator (Entidade Reguladora dos Serviços Energeticos, or, ERSE, in Portuguese) a new remuneration scheme for the subsequent years. The motivation comes from the need to cut the National Electricity System (SEN) deficit, and is reinforced by the "Memorandum of understanding on specific economic conditionality" (MoU) issued by the Troika (European Commission, International Monetary Fund and European Central Bank), which expresses the need to limit the policy costs of renewables (EC, 2013a, 2013b; EC et al., 2013).

Recently, the Ministry of Economy and Employment called upon a redesign once again the FIT scheme and claimed that "not all the expenditures associated with the support of renewable energy generation technologies have been passed on to electricity consumers" (Diário da República, 2013), which could lead to an increase of the deficit of the National Electricity System (SEN) (Diário da República, 2013). Negotiations between the regulator and stakeholder groups resulted in the publication of a new legislation in 2013 that aims to reduce urgently part of the electricity system deficit. The 2013 legislation includes an annual payment to the regulator, and in exchange offers the opportunity to increase the period of the FIT payments. There are two levels of possible annual payments from the wind IPPs back to National Electricity System (SEN): a 'low payment' equal to $6700/MW-installed and a 'high payment' equal to $7500/MW-installed, either of which are paid annually for eight years. The 'low payment' offers a FIT extension of five years and the 'high payment' offers a FIT extension of seven years.[5] This extension period starts in 2020 for old parks (connected on or before 2005). Parks connected after 2005 will keep receiving the current FIT of approximately $105/MWh for 20 years or until the park produces 44 GWh of generation per MW of capacity installed — counted from the year of connection, instead of 15 years or 33 GWh, as previously established in 2005 legislation. Thus, the option to further extend the FIT for five or seven years in exchange of payments to the SEN is as well available to new wind parks, and the extension period starts counting between 2026 and 2029 depending on connection year (see Fig. 2 for details). The FIT offered for the additional period is designed to equal the level of spot electricity market prices. In any case, the levels of incentives are designed so wind power producers receive higher revenue than the

[3] The FIT formula in 1999 and 2001 was the same except for a coefficient to differentiate renewable energy technologies. Assuming a capacity factor of 0.20, a given wind park would receive 23% more under the formula established in 2001 than under the formula established in 1999.

[4] A green certificate is the name given in Europe to U.S. renewable energy certificates (RECs). In Portugal, these are certificates that are issued by the Grid Operator (REN) and can be traded in a separate market, leading to additional profits to renewable energy generators. Nevertheless, wind parks under the FIT system cannot trade green certificates.

[5] The terms 'low payment' and 'high payment' are not textual from the legislation, but are used by the authors to describe better its details.

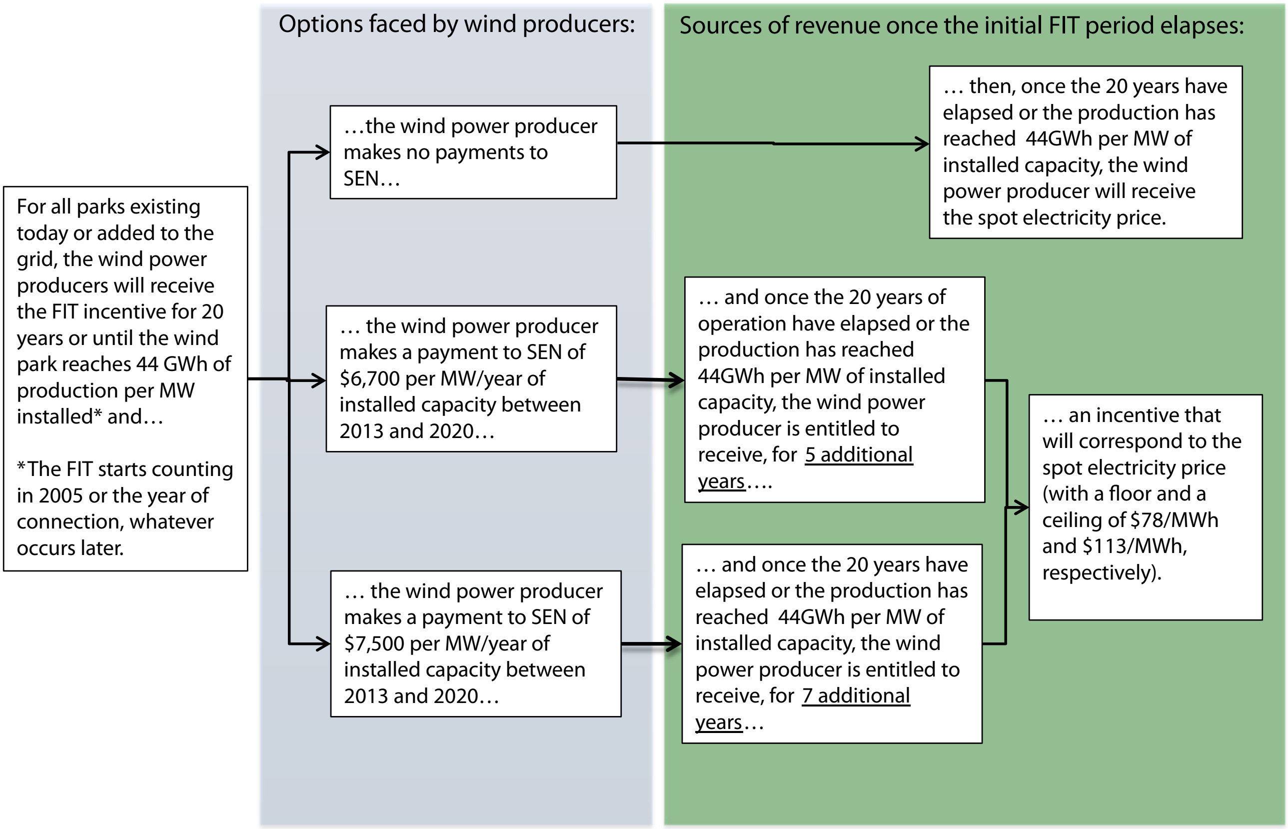

Fig. 2. Possible remuneration schemes currently available for existing wind parks in Portugal.

payment they need to make back to the regulator. For instance, assuming a capacity factor of 0.20 and the low FIT offered of $85/MWh a wind IPP will receive approximately $150,000/MW per year of FIT extension (or $44,000/MW compared to a $60/MWh electricity price), and will have to pay $6000/MW back to the regulator.

Wind IPPs can also choose not to receive the FIT extension of five to seven years, in which case they will not need to make the annual payments back to the National Electricity System. Thus, if this option is chosen, parks connected on or before 2005 will start receiving the spot electricity market price by January 2020. Similarly, wind parks connected between 2006 and 2010 will start receiving the spot electricity market price between 2026 and 2030 respectively, assuming the limits of production are not met at that time.[6] Fig. 2 highlights different strategies that wind IPPs can consider as a result of Decree-law 35/2013.

Total cumulative spending in the form of wind FITs between 1992 and December 2010 is reported to have been approximately 4.1 billion dollars (ERSE, 2011), or about 1.5% of national Portuguese annual gross domestic product (GDP) (WB, 2013), and slightly less than 1% of Portugal external debt (Banco de Portugal, 2013).

The energy policy for wind included several goals and requirements for participants in this market. For example, in the public tender of 2005 one of the award criterions was to use wind energy to leverage the creation of a new industrial sector through an obligation to provide investment and employment in some of the country's less favored regions, to encourage the transfer of technology to Portugal from abroad and to create a new source of export of goods, limiting the import of wind turbines (ENEOP, 2009). ENEOP, Eólicas de Portugal SA, won the first and the largest phase of this bid, and it reports that the criterions established by the public tender for job creation, R&D funding allocation and the creation of an industrial cluster were met (Eneop, 2009a; Eneop, 2009b; Eneop, 2009c). More details regarding each of these aspects are provided in the SI.

In Fig. 3, we show the multiple extensions provided over time to IPPs for the period over which they are entitled to receive FITs. For example, parks connected in 1992, were originally expected to stop receiving FIT incentives after 12 years, i.e., by 2004. However, with the 2005 law the incentive was continued until 2012 (the expected last year of operation of those plants). Similarly, plants connected in 2006 were originally expected to receive the FIT incentive for 15 years, i.e., until 2021, according to the 2005 law. By 2013, however, a new law extended the period to 20 years, and thus, those plants connected in 2006 will be receiving FIT incentives until 2026. Moreover, after that period they can choose to extend for another five or seven years the incentive in exchange of payments to SEN for eight years.

Despite the positive impact in terms of greening the Portuguese electricity grid, there is still an open question of whether the mechanisms and incentives set in place could have been designed in a different way, while achieving the same amount of electricity produced from wind. In particular, the issue arises of whether the design of the FITs was such that IPPs were over-compensated, and the same results could have been achieved at much lower costs to Portuguese consumers. This paper has two goals: to estimate the profits made by wind IPPs that connected to the grid from 1992 to 2010 (the most recent year for which investment data is available) and to make recommendations on how to design a policy that could provide similar outcomes while reducing public spending in the future.

2. Methods

We assess the profitability of wind energy in Portugal in two ways: by computing the net present value (NPV) of all wind projects and by

[6] 33 GWh and 44 GWh per MW installed corresponds to a capacity factor of 0.25 over 15 and 20 years, respectively. Because the national average capacity factor over 2006–2010 was 0.23 we assume in our analysis that the production limits are never met, and the FIT period is determined by years of production.

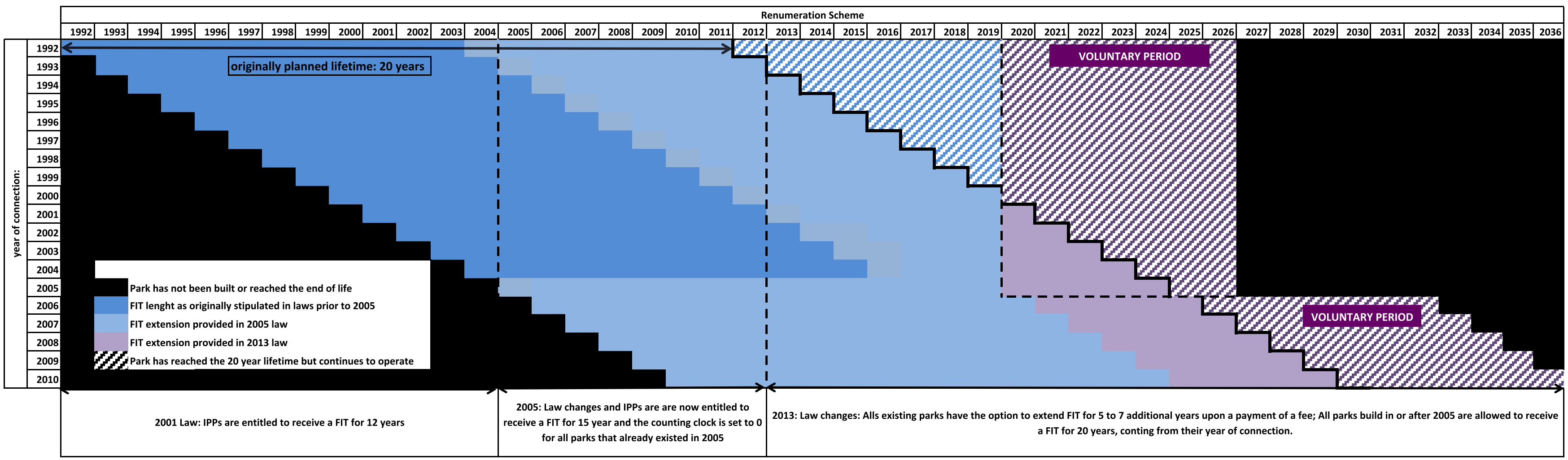

Fig. 3. Extensions of FIT remuneration period by several Portuguese laws over time.

comparing the annualized revenue with the levelized costs of electricity (LCOE) for parks added each year from 1992 to 2010. Our analysis ends in year 2010 as that is the most recent year of publicly available data on investment costs. While additional capacity from wind will be added in Portugal in the near future, in this paper we limit our analysis to built capacity as of December 2010.

Both NPV and a comparison between annualized revenue and LCOEs provide similar messages. For example, in the NPV analysis, we estimate the NPV for different market clearing prices p received by the wind IPPs after the FIT period is over. In the annualized analysis we estimate the p that would make the wind park to break even. We aggregate projects by year of connection, and we use the annual national average capacity factor to estimate wind generation.

2.1. Levelized annual costs and benefits

We assess the equivalent annualized profits (in \$2005/MWh), i.e., annualized revenue minus annualized costs. Annual revenue corresponds to the FIT value in the years where the IPPs have access to a FIT (\$2005/MWh), and to the spot electricity price p in the years thereafter. Annual costs correspond to the levelized costs of electricity, or LCOEs. Thus, annualized profits (\$2005/MWh) for wind farms installed in year i, AP_i, are computed as follows:

$$AP_i = AR_i - AC_i$$
$$AR_i = \frac{\left[\sum_{k=i}^{i+T} \frac{((1-muni) \times FIT_k) \cdot gen_k}{(1+r)^{k-i}} + \sum_{k=i+T+1}^{lif\,etime} \frac{p_k \times gen_k}{(1+r)^{k-i}}\right] \cdot CCR}{\sum_{i=y}^{lifetime} gen_i}$$
$$AC_i = \frac{I_i \cdot CCR + O\&M_i}{\sum_{k=i}^{lifetime} gen_k} \tag{1}$$

where AR_i and AC_i are the annualized revenues and costs for wind parks installed in year i (\$2005/MWh), and gen_k is the annual electricity generation (MWh) in year k by parks installed in year i. FIT_k is the average annual national FIT payment in year k (\$2005/MWh), paid for period T. $muni$ (in \$2005/MWh), represents the payments that wind IPPs have to make to the municipality, which correspond by law to 2.5% of total revenue during the FIT period, and p_i is the spot electricity market price (\$2005/MWh) that wind producers receive after the FIT period is over. (Diário da República, 2005, 2013). CCR is the capital recovery rate, $\left(\frac{r}{1-(1+r)^{-lifetime}}\right)$, where r is the discount rate. I is the total investment costs (\$2005) incurred by projects connected in year y, including foundation, road, land and grid connection. We assume a one year lag time to take into account construction time, i.e. projects connected in 1993 incur investment costs of 1992. Due to lack of available data for Portuguese investment costs, we used Danish investment costs from 1992 to 2002 (EWEA, 2009) and Portuguese investment costs from 2003 to 2010 (IEA, 2010). While there is uncertainty associated with these values, there is a correlation of 0.95 of Danish and Portuguese investment costs for years where there is overlapping data, i.e., from 2003 to 2006, which justifies the use of Danish wind investment data. It is important to notice that real Portuguese investment costs might be higher than Danish's for 1992–2002 because Danish wind industry was more mature by the 90's compared to Portugal. Nevertheless, because by 2002 there was very little wind capacity installed in Portugal, we are confident that an underestimation of Portuguese costs from 1992 to 2002 does not affect the overall results. However, the correlation for investment costs only exists for the overlapping period of four years, and so it may be the case that we are under or overestimating the costs for Portugal in our analysis. Given this key limitation, we perform a sensitivity analysis to test our results taking into account higher investment costs over all the period analyzed. $O\&M$ are total annual maintenance and operation costs, assumed to be constant (in \$2005 values) over the *lifetime*.

2.2. Net present value

We supplement the annualized analysis with the net present value for wind independent power producers for the poll of wind plants in operation between 1992 and 2010, by year i in which they were installed. It is computed as:

$$NPV_i = \frac{\sum_{k=i}^{i+lifetime} \frac{TR_k - TC_k}{(1+r)^{k-i}}}{\sum_{k=i}^{i+lifetime} gen_k} \tag{2}$$

where NPV_i represents the net present value over the lifetime (*lifetime*) for all parks installed in year i (in \$2005/MWh), TR_k is the total revenue in year k, and TC_k is the total cost in year k. TR_k is given by $(FIT_k \times gen_k)$ during the years where wind parks are entitled to receive FITs, and to the spot electricity price p otherwise.

We normalize the NPV by the amount of electricity generated by the existing wind parks connected in year k over their lifetime, thus gen_k is the amount of electricity generated by wind parks connected in year k. The results for the NPV analysis are included in the Supplementary data (SI).

Total costs include investment costs, O&M fixed costs (in \$2005 values), and the municipality payment equal to 2.5% of total revenue received.

2.3. Scenarios

The scope of this paper is to focus only on existing wind parks, i.e., parks that were in operation by 2010. We assume that parks have a 20-year lifetime. From 1992 to 2010, we use historical data on wind parks location, average annual capacity factors, costs and FIT levels. As explained in the previous section, underlying law followed by IPPs was recently changed in Portugal, such that parks connected on or before 2005 can choose to extend the period they receive a tariff by five or seven additional years at the end of their 15-year FIT period, as long as they make a payment now back to the regulator as a way to reduce the current funding deficit Portugal endures in the electricity system. Since the regulatory system covering wind IPPs has been regularly updated and changed over time, we consider four scenarios for the period 2013 to 2029 (last year of generation for the newest parks considered). Specifically, we assume several ranges of values for the spot electricity prices p wind power producers will receive in the years in which they are operating but not entitled to receive a FIT. This situation starts occurring in January 2020 for the older wind parks, when their 15-year FIT period expires. We also consider potential future revisions to the current law by assessing the consequences of shortening the period that wind IPPs are currently entitled to receive the FIT. In addition, we consider a fifth scenario in which we assess the relevance of the recent changes under Decree-Law 35/2013 versus the previously ongoing legislation. In all cases, for years before 2010, we use historical data. For years 2011 and onwards, we consider the following scenarios:

- *Scenario 1*: This scenario considers a case where Portugal would have decided to keep their 2005 law. This would mean that all parks would have 15 years worth of incentives, starting counting in 2005, no matter how long they had already been receiving incentives. This scenario shows what would have occurred if the government had decided not to implement the 2013 legislation.
- *Scenario 2*: Same as scenario 1, but assuming the government had decided to shorten the time of FIT incentive from 15 years to 12 years. This scenario highlights wind parks that can end the FIT and be competitive in the next few years. Projects that have received already a FIT for more than 12 years would then be having their FIT incentives ending now — i.e. by December 2013.
- *Scenario 3:* Assuming the FIT system would end at the beginning of 2014 for all wind parks, regardless of the year of connection. This

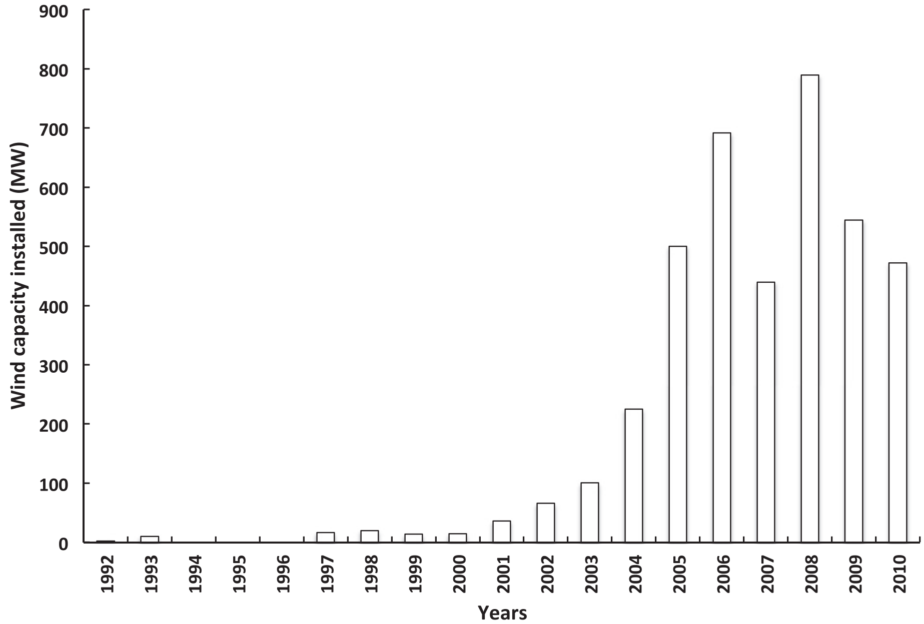

Fig. 4. Portuguese wind power capacity added annually (MW) between 1992 and 2010 (ERSE, 2011).

scenario shows whether projects would be profitable if they enter now the Iberian competitive electricity market.

- *Scenario 4:* Since the average national FIT paid over the past five years is $105/MWh, we include a scenario in which a fix FIT equal to $105/MWh is offered to all wind parks for 15 years. This scenario highlights a simpler approach that a policy maker could use instead of the current FIT formula system: a fix tariff and fix period.
- *Scenario 5:* We simulate the effects of the legislation established in 2013, in which FIT period is extended in exchange of a "payback payment" from the wind IPP to the SEN, and we assess how the new changes in the policy impact profitability of wind parks. All wind parks are considered to incur extra investment costs in December 2019 to operate over all the period analyzed, as their lifetimes are extended (see Introduction for details). These costs are assumed to be 35% of 2010 reported total investment costs (IEA, 2010), representing the replacement of gearbox, transformer and generator — or 50% of total turbine costs (EWEA, 2009). Further assumptions are: payment of extra investment costs over five year period, 10% discount rate and fix O&M costs of $5/MWh.

For all the scenarios, after the FIT or extended incentive period is over, we assume IPPs are required to be players in the market, and receive the spot electricity price p. Spot electricity market price, treated as a parameter: $0/MWh, $30/MWh, $60/MWh, $90/MWh and $105/MWh.

3. Data

Portugal's first wind turbine was installed in 1992. By 2010, Portugal had approximately 4000 MW of wind capacity installed (ERSE, 2011). Fig. 4 shows wind capacity added in the country between 1992 and 2010. By December 2001, there was less than 100 MW installed in wind capacity, distributed in 7 of the 28 NUTS II[7] regions of Continental Portugal. In contrast, by 2010, Portugal had 40 times more wind capacity installed across 22 of the 28 continental regions. Portugal had by December 2010 approximately 0.4 kW of wind power installed per capita (ERSE, 2011; INE, 2011), whereas other wind power leaders, such as Denmark, Germany, U.S. and Spain, which had by 2010 approximately 0.7 kW, 0.3 kW, 0.1 kW and 0.4 kW of wind power installed per capita, respectively (AEE, 2013; AWEA, 2013; BWE, 2013; DEA, 2011).

Total Portuguese wind investment costs (including turbine and foundation costs) are reported from 2003 to 2010 by IEA, 2010. For lack of better data, we use data from 1992 to 2002 from Denmark since the correlation in the overlapping period 2003–2006 is 0.95. Fig. 5 shows investment costs for Denmark from 1990 to 2006 and for Portugal from 2003 to 2010. Projections of the European average wind investment costs are also shown in Fig. 5, but were not used in the analysis due to the large discrepancy when compared with Portugal data for the overlapping years. The variability of data reported by the IEA on Portuguese wind investment costs is likely due to a shortage of wind turbines in years of high demand (between 2006 and 2010) and a high FIT that could motivate wind turbine manufacturers to charge higher prices (ERSE, 2012).

We use an average annual national capacity factor to estimate the generation of all wind parks connected in a particular year due to lack of data availability of capacity factor by location. To the extent of our knowledge, there is no public available data from the same source on wind capacity installed and wind power generation by region and across time. Only national data for generation and capacity installed is publicly available, as shown in Fig. 6.

We assume constant and equal O&M costs across all wind parks, regardless of their year of connection because of the lack of data, and test that assumption in the sensitivity analysis. Wind maintenance companies in Portugal report O&M costs[8] as low as $8000/MW per year (Anon, 2012), representing average maintenance costs of $4/MWh. Other estimates range from $9/MWh to $27/MWh (reviewed sources: (EWEA, 2009),(NREL, 2012), (IRENA, 2012)). Reductions of 40% in O&M costs are reported between 2008 and 2012 in a study covering 38 developers and service providers in more than 20 markets in Europe (BNEF, 2012; EurObserv'ER, 2012). We assume $5/MWh, but include a sensitivity analysis for which O&M costs are as high as $25/MWh for all wind parks over all their lifetimes to cover all possible levels.

[7] The European Commission classifies the European Territory according to the NUTS classification (Nomenclature of territorial units for statistics). According to NUTS I, Portugal is divided into three regions (Continental, Azores and Madeira). According to NUTS II, Portugal is divided into seven regions (Regional Coordination Commissions and Autonomous regions). According to NUTS III Portugal is divided into 30 municipalities. Since our analysis is for Continental Portugal, we cover 28 municipalities.

[8] All values reported were translated into $2005 constant values.

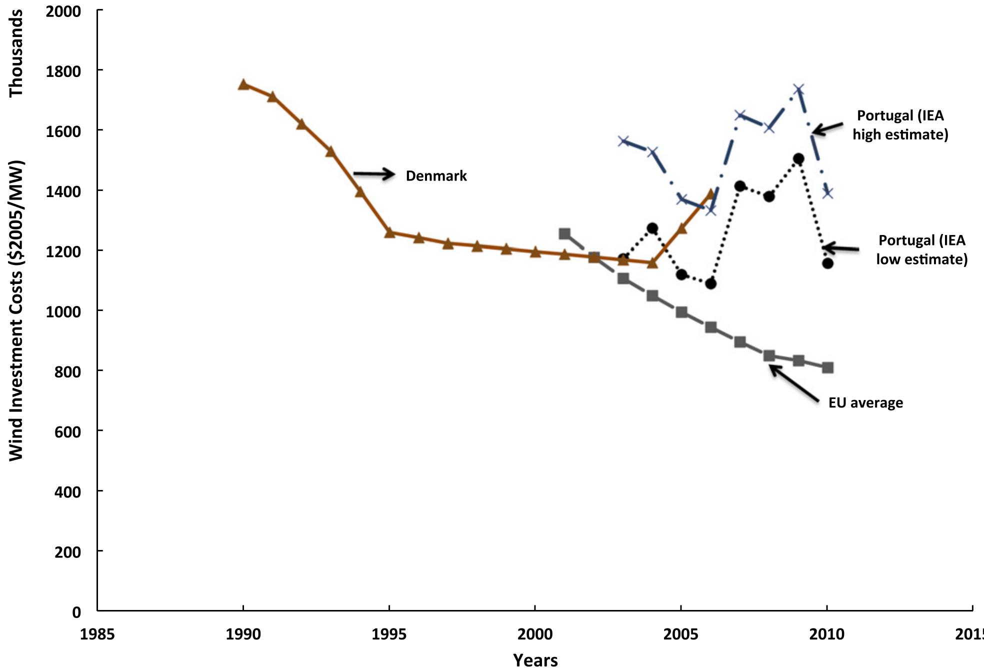

Fig. 5. Wind investment costs in Denmark (EWEA, 2009), Portugal (IEA, 2010) and for the EU projected average (Zervos, 2003) between 1990 and 2010.

4. Results

Unless otherwise noted, basic assumptions used for these estimates are 10% discount rate, 20-year lifetime, $5/MWh of O&M costs and a loan payment over a 20-year period.

4.1. Annualized flows, by year of connection

Fig. 7 shows annualized revenues and costs over the wind parks' lifetime for parks connected for each year between 1992 and 2010, by year of connection. Parks with LCOEs higher than the annualized revenues would have economic losses. For instance, under the assumptions we used for this simulation, which appears to be the case for parks connected in 1992 and 1993. However, it is unlikely these projects have not recovered their costs: in our simulations we assume 10% discount rate and annual capacity factors equal to average national. Lower discount rates lead to positive NPVs for these early projects (see Sensitivity analysis). In the Supplementary Information we provide details on the NPV by connection year.

Are the existing wind parks being oversubsidized? Under all scenarios, all parks connected from 1997 to 2007 have net revenues, and thus have likely been oversubsidized. Note that our assumption has been fairly conservative concerning discount rates, so the parks may have been even more oversubsidized than what our results show.

Could all parks be competitive without a feed-in tariff? For wind parks built recently, i.e., from 2008 onwards, removing entirely the feed-in-

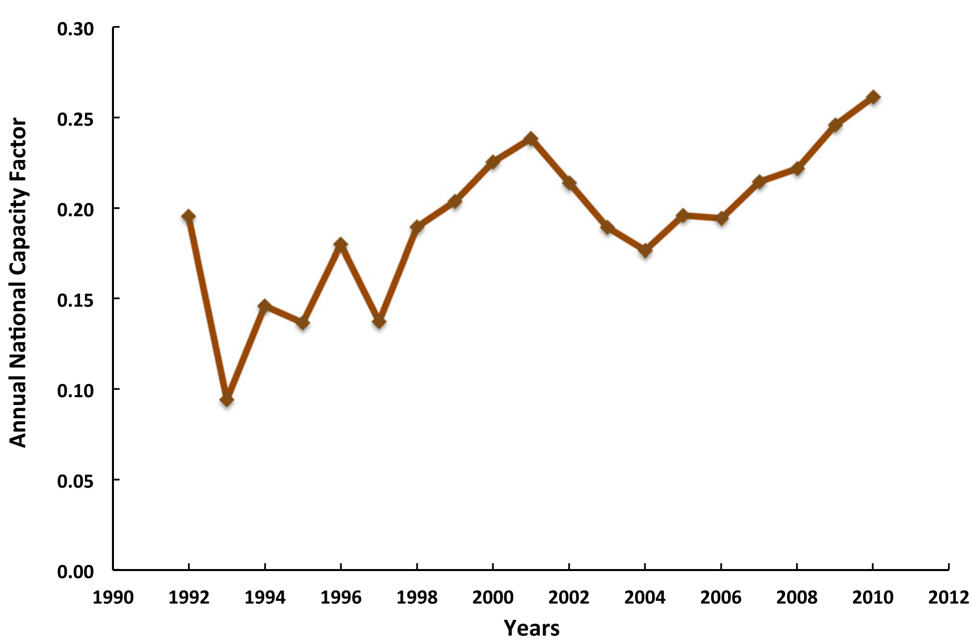

Fig. 6. Average capacity factor for wind farms in Portugal from 1992 to 2010 (ERSE, 2011).

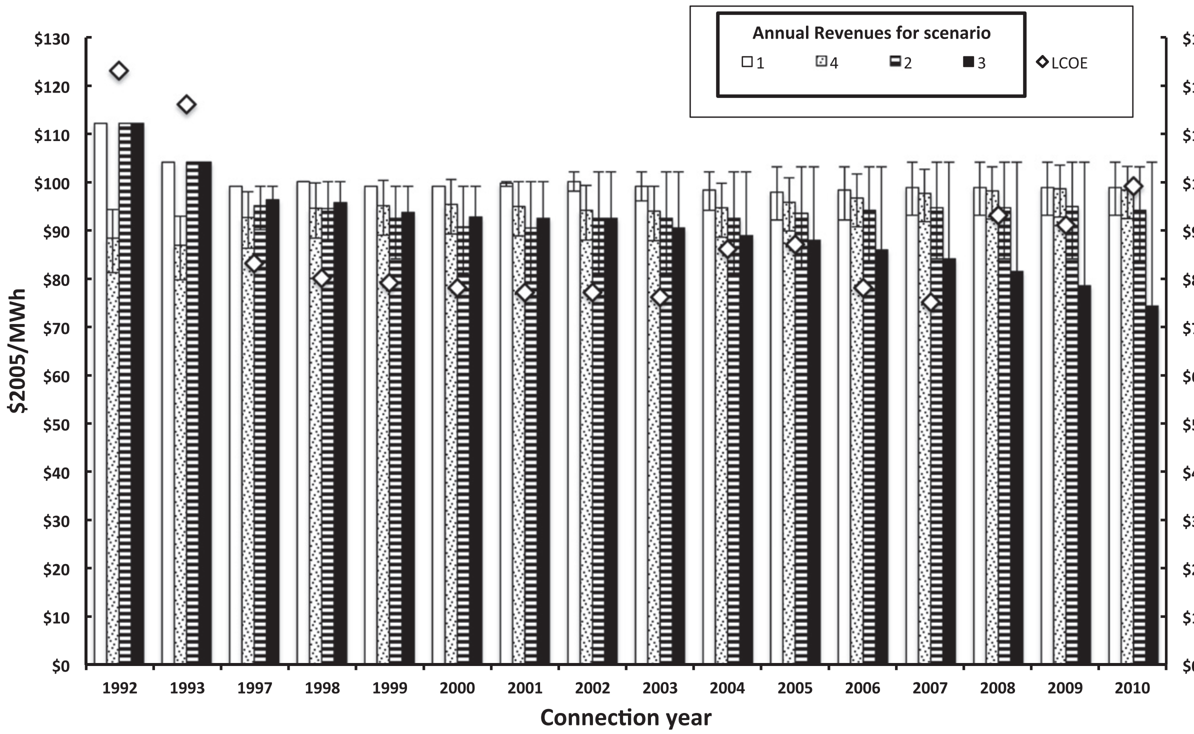

Fig. 7. Annualized revenue and annualized costs (LCOE) ($2005/MWh), for Scenarios 1 through 4. The ranges for each bar are not error bars, they instead correspond to different assumptions of spot market prices, ranging from $0/MWh to $105/MWh. 1 = scenario considers a case where Portugal would have decided to keep their 2005 law (all parks would have 15 years worth of incentives, starting counting in 2005, no matter for how long they had already been receiving incentives); 2 = same as scenario 1, but assuming the government had decided to shorten the time of FIT incentive from 15 years to 12 years; 3 = assume the FIT system would end at the beginning of 2014 for all wind parks, regardless year of connection; 4 = a fix FIT of $105/MWh is offered to all wind parks for 15 years.

tariff (Scenario 3) and requesting these parks to receive the spot market would not be economically viable. However, for all wind parks but the 1992/1993 ones, moving towards a schedule where feed-in tariffs are provided at the current level only for 12 years (Scenario 2) would be enough for IPPs to recover their costs. Parks connected in 2010 are the only ones that would require spot electricity prices to be on the high end in order to be economically viable.

Should Portugal have kept the 2005 legislation unchanged? As noted previously, the 2005 legislation provides FITs for 15 years or until the park generates 33 GWh/MW installed (Scenario 1). All wind parks under 2005 legislation are competitive under this scheme, except the ones connected in 2010. For parks connected in 2010, spot electricity prices have to be higher than $60/MWh for them to be economically viable once the 15-year of FIT ends.

4.1.1. Under the alternative policies assumed, what is the minimum price once parks have to compete in the Portuguese electricity market (OMIP) to be profitable?

In all scenarios, if we assume that spot prices are equal to average current OMIP spot prices, all wind parks built prior or on 2007 are competitive in the market. If 2005's legislation had been maintained (Scenario 1), we find that all parks would be able to be economically competitive even at very low OMIP spot prices — because investment would have been recouped by the time they stop receiving FITs.[9]

Could Portugal have established a simple fixed FIT equal to $105/MWh for 15 years for all projects? Yes. If wind parks would have received a FIT only for 15 years and equal to $105/MWh, they would have recovered their lifetime costs and be competitive by year 16th of production.

What could have been an optimal level of FIT? In addition to our analysis considering the first four scenarios, we estimate the NPV for different values of a hypothetical FIT paid over the 20-year lifetime of wind parks, by year of connection. Our motivation to do this analysis comes from the recent changes in the FIT legislation, in which the FIT period was increased to 20 years in Portugal – equal to the lifetime we assume for the parks. Thus, before considering the specifics of the new legislation, it is relevant to estimate the minimum fix FIT that wind parks could receive over all their production years to cover all costs. Fig. 8 shows the decision investment space of wind power investors. It depicts NPVs ($/MWh) under different assumptions on investment costs and life-long FIT, tabulated in black for investments with negative NPVs and in white with positive NPVs. For instance, 2010 projects need a lifetime-long FIT of approximately $100/MWh in order to cover its costs. New projects (assuming 2011 investment costs) need a much lower FIT, below $80/MWh to be economically profitable.

How much will the Portuguese government spend in wind subsidies, and what could be the alternatives? If we sum up investment and operating cost for all wind capacity connected between 1992 and 2010 this amounts to $4.54 billion (in $2005). Under the 2005 legislation (Scenario 1) the Portuguese government would have spent around $4.8 billion. Thus, wind is oversubsidized. The 2013 legislation offered an even worse outcome of public spending: an additional spending of $840 million, representing more than $200,000 extra spending per MW installed. All municipalities will receive between $120 million and $135 million in total over all wind parks' lifetime. However, we are not accounting for environmental externalities avoided by increasing wind, savings and security gains achieved by substituting primary energy imports through the use of wind resources, and job creation, all of which will attenuate differences between government spending and the costs faced by investors (see CO_2 cost-effectiveness and further issues section for more details on this). As benefits arise, other costs also do appear as well, mainly concerned with the underutilization of already existing traditional power plants, the effects on the spot electricity market price and the level of residential electricity rates

[9] Exception being 2010 parks.

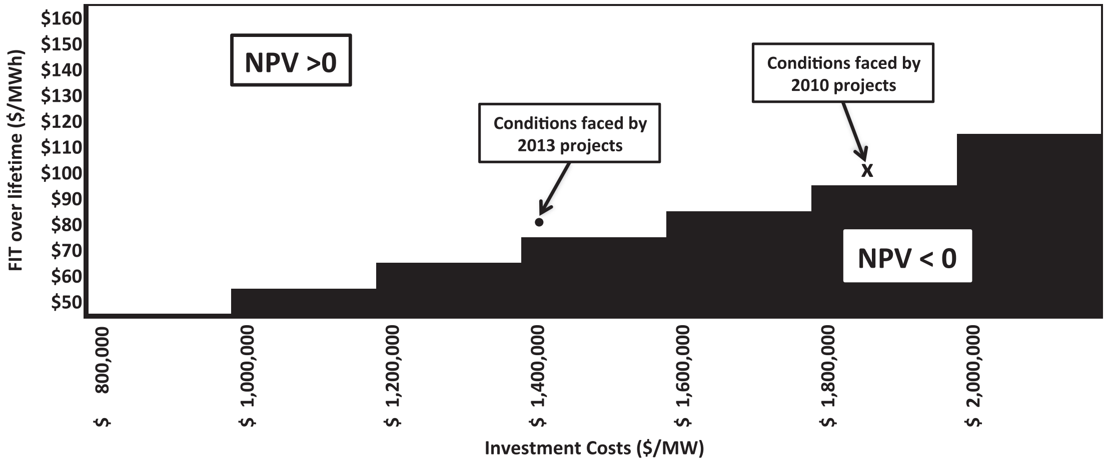

Fig. 8. NPV ($/MWh) of wind parks for different investment costs and fix FITs paid over 20 years. Basic assumption of discount rate 10%, 20 years lifetime and O&M costs of $5/MWh are used.

due to the support of renewable sources. These benefits and costs are not included in our analysis.

Consequences of the changes to Portuguese FIT, starting February 2013. Decree-law 35/2013 establishes generous and unnecessary conditions to existent wind IPPs in exchange of immediate payments to the SEN that guarantee liquidity to cover the deficit. This approach guarantees that SEN receives payments for the next eight years, but at an overall higher cost to the country — this cost is just transferred to the future. All wind IPPs that can incur the additional investments needed to extend the lifetimes, will benefit from accepting this agreement. This is particularly true because all wind capacity installed will have already recovered initial total investment costs by the time the extension period starts, and will still receive a high tariff over $80/MWh. In the Supplementary data we show NPV under the new conditions presented in DL35/2013. All wind parks are considered to incur extra investment costs in December 2019 to continue to operate, as their lifetimes are extended (see Introduction for details). These costs are assumed to be 35% of 2010 reported total investment costs (IEA, 2010), representing the replacement of gearbox, transformer and generator (EWEA, 2009). Further assumptions we make include: payment of extra investment costs over a five year period, a 10% discount rate, and fix O&M costs of $5/MWh. Compared to the BAU scenario, wind parks will have NPVs that are larger by at least 6%, but can be as large as threefold.

4.2. Sensitivity analysis

We perform a sensitivity analysis on the Business as Usual Scenario, BAU (i.e. Scenario 1). We find out that results are sensitive to the discount rate and the initial investment costs. Positive NPVs are achieved for a wide interval for all variables. The average NPV is approximately $5/MWh, and varies between $10/MWh and $26/MWh for discount rates of 15% and 5% respectively, and between $8/MWh and $15/MWh for a 10% change in investment costs. A low discount rate of 5% has almost double the impact in increasing the NPV than a 10% reduction in investment costs. This shows that appropriate financial mechanisms that maintain discount rates low are more important than promoting incentives to reduce investment costs. It also highlights that high O&M costs play an important role in the profitability level of the projects, and current and reliable data on these costs is increasingly important to properly implement a reduction in FIT levels. We are confident that our basic O&M assumption of $5/MWh is reasonable because it leads to zero NPVs for 2010 projects, which in fact made the decision investment.

Increasing the capacity factor by 10%, making O&M costs negligible or assuming an average clearing market price of $90/MWh, all have similar impacts — resulting in a twofold increase in NPVs. The fact that the clearing market price has low impact on the NPVs corroborates the feasibility of reducing or eliminating FITs and leaving wind power plants to receive the clearing market price. Lastly, since average Portuguese capacity factors are low, a reduction of only 10% in capacity factors can lead to negative NPVs.

4.3. CO_2 cost-effectiveness and further issues

We estimate the cost of avoided CO_2 by wind electricity generation. To estimate the amount of avoided CO_2, we assume that wind power displaces electricity from the average generation mix — including other renewables. Imports are not accounted for, which corresponds to about 8% of total electricity consumption[10] (DGEG, 2011). The cost of wind electricity generation corresponds to LCOE values presented in Supplementary data.

Fig. 10 shows the cost-effectiveness of wind power in terms of annualized cost per ton (investment and O&M) of avoided CO_2 emissions. Results are presented by connection year and vary between $140/ton CO_2 and $510/ton CO_2. This is assuming wind is displacing the average electricity mix. The cost of avoided CO_2 increases as investment costs increase or the amount of avoided CO_2 decreases. Thus, at higher wind penetration rates less CO_2 emissions are displaced. For instance, 2010 projects are the least cost-effective as those projects incurred the largest investment costs, and displaced less emissions than projects connected earlier on — when oil and coal generation were more intense. Our lower and upper limits still refer to the average electricity mix in that year, but we changed the minimum and maximum emission intensities for different energy sources as assumed by IEA.[11] We assume that wind projects displace annually the same amount of emissions as the year they connected. This is a fair assumption because electricity demand is expected to increase only 1.4% up to 2030, when the last wind park considered in this analysis will end its lifetime. This assumption may result in an overestimation of CO_2 emissions avoided for late years, especially after 2025 when all coal electricity production will be replaced by gas power

[10] Electricity imports have averaged 8% between 2000 and 2010, with a maximum of 17% in 2008 (a dry year).

[11] For CO_2 intensity values range between 715 and 920 g/kWh, 370 and 500 g/kWh, and 610 and 620 g/kWh for coal, gas and oil-based power plants respectively (IEA, 2011). The estimated range of CO2 intensity of the Portuguese electricity sector includes the values reported by the Portuguese Institute of Statistics (INE, 2012).

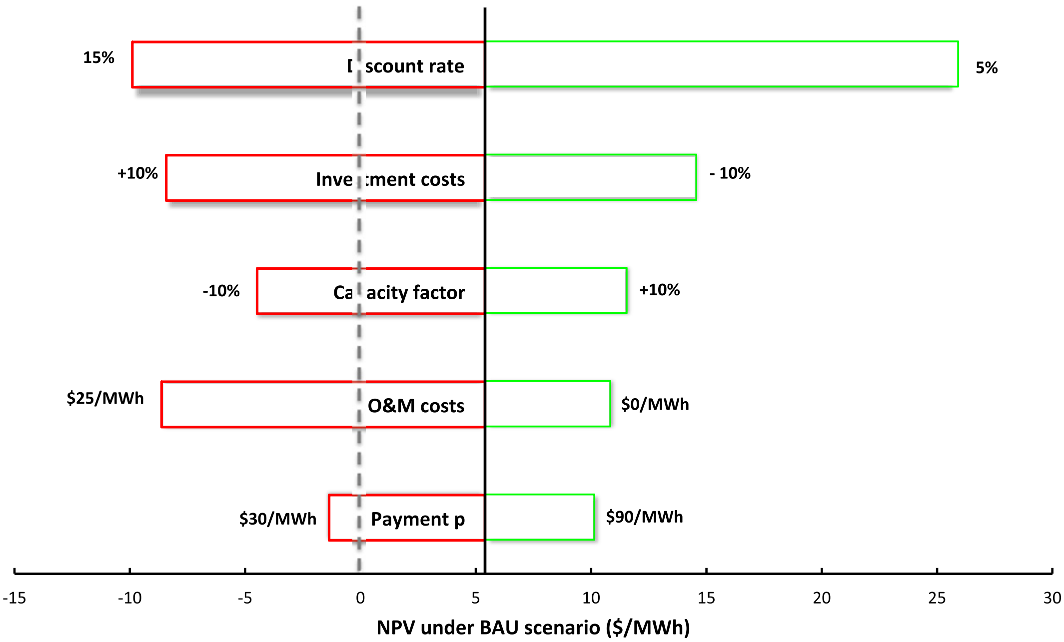

Fig. 9. Tornado diagram of Scenario 1, corresponding to NPV ($/MWh) of wind parks. Base case assumptions: 10% discount rate, average national investment costs and capacity factor, $5/MWh O&M costs, p = $60/MWh and 20-year lifetime.

plants, and the total thermal based electricity production will decrease to 32% — compared with 46% by December 2011 (DGEG and REN, 2013). Thus, costs of avoided emissions for projects that will be operating after 2025 (those connected in 2006–2010) are expected to be higher than our estimates. (See Fig. 9.)

Just for the sake of comparison, if we were to assume that wind was always displacing coal, the cost-effectiveness would range from $80/ton CO_2 to $330/ton CO_2.

Since Portugal has historically been a country with a high share of renewables, accounting for a share between 15% and almost 50%, the cost-effectiveness estimates are high — on average approximately $220/ton CO_2.

Portugal's case proves how important technology performance and the selection of wind locations are determinant in the cost-effective estimates. For example, even though investment costs for years 1993 and 2010 are very similar, and in 2010 there was a larger

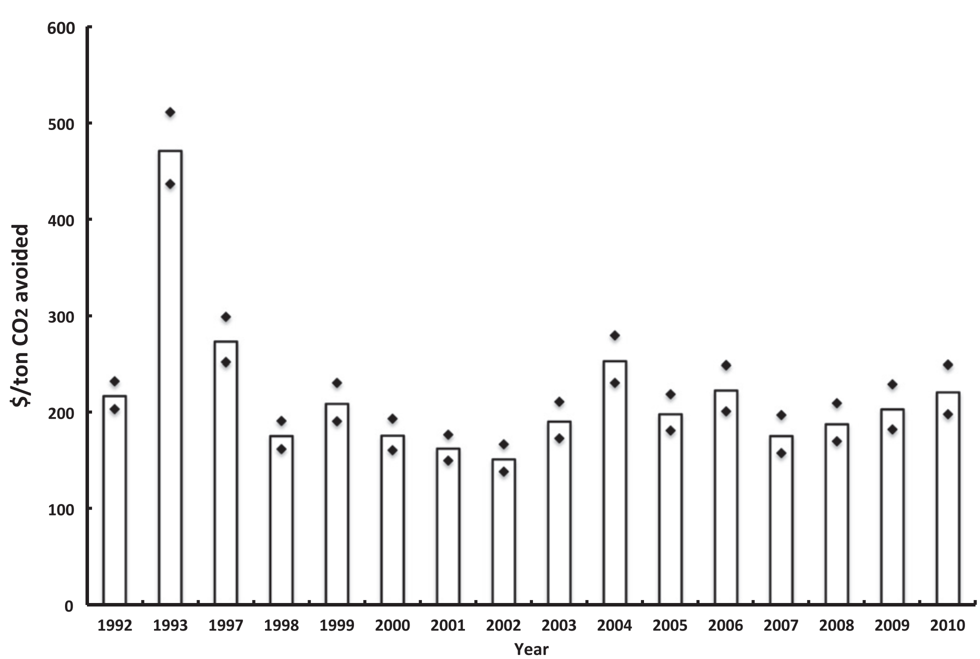

Fig. 10. Cost-effectiveness in $/ton of CO_2 avoided by wind power in Portugal, by connection year. Assumptions for cost estimates: 20-year lifetime, 10% discount rate, O&M $5/MWh. Assumptions for CO_2 emissions estimates: CO_2 intensity in Portugal of coal-based power plants 818 g/kWh, of gas-based power plants 435 g/kWh and of oil-based power plants 615 g/kWh. Further assumptions: wind power displaces electricity from the annual average electricity mix and annual capacity factor of each wind project equals national average annual capacity factor up to 2011 and afterwards equals 0.23. The dots correspond to low and high bounds for CO_2 intensity when computing the intensity of the Portuguese electricity mix: 715 and 920 g/kWh, 370 and 500 g/kWh, and 610 and 620 g/kWh for coal, gas and oil-based power plants respectively (IEA, 2011).

share of renewables in electricity production (48% in 2010 vs 30% in 1993), the cost estimates for 2010 are significantly lower than those of 1993 projects. This is because capacity factor improved significantly from 1993 to 2010, from 9% to 26%.

Wind is generally also suggested as a strategy to promote energy independence. Electricity accounts for approximately 30% to 40% of all final energy consumption, and wind power accounted for 17% of this by December 2010. Thus, wind power accounted for about 6% of total primary energy consumption in the year with the largest wind penetration. Although wind power is part of the energy independence path, other measures such as efficiency and transportation policies also need to be pursued if energy independence is to be achieved.

Thus, increasing wind power may, to some extent, result in a reduction in fuel imports, even in the case that fossil fuel prices decrease. A decrease in fossil fuel prices would result, in the short term, in lowering marginal generation costs of fossil fuel generation, i.e. lowering spot electricity prices. However, from a national energy security perspective and to meet environmental goals, one could still foresee wind power playing a role.

There were multiple goals that Portugal aimed to achieve by promoting the growth of the wind sector in the country. Those included job creation, technology transfer and innovation, the creation of an industrial cluster (see *Additional details on wind policies in Portugal*, in the Supplemental Information). The benefits and the costs associated with these strategies are not incorporated in our analysis, as our goal was to quantify strictly the economic profits arising from the payment of wind feed-in tariffs, and that this is independent of other costs and benefits that the promotion of wind power has brought to Portugal.

5. Conclusions and policy recommendations

Decree-Law 33A-2005 guarantees a FIT paid to wind IPPs until December 2019 for parks that connected to the electricity grid on 1992–2005, and until 2021–2024 for parks that connected between 2006 and 2010, respectively. After that, it dictates that wind parks will receive a price for production equal to the average annual spot market price plus green certificates if available. We find that under the 2005 legislation, all projects connected in 1997 and onwards will have a positive NPV if they enter the competitive electricity market, and the total spending in FITs is larger than needed. This means that wind power has been oversubsidized and that starting 2020, wind parks could instead be players in the spot market.

Portugal could have cut spending in the form of FITs by decreasing the FIT period from 15 to 12 years (Scenario 2) — and wind parks would still be economically profitable. Only more recent projects (2008–2010) would need to receive in average a market price larger than \$30/MWh to have positive NPVs. The fact that under the hypothetical scenario of Portugal ending the FIT payments by December 2013 still leads to positive NPVs for all projects connected up to December 2007 (assuming they receive in average a market price of at least \$30/MWh starting January 2014) is an indicator of the over subsidization of the wind FIT scheme and a need to assess alternatives and move forward with policy innovation.

However, Portugal published a recent reform arguing the need to cut SEN deficit. Instead of cutting FITs (which are increasing the deficit), the government increased them in exchange for immediate payments from the wind producers to the electricity system. In reality, these reforms are transferring the deficit into the future, resulting in a more expensive and unsustainable approach. In fact, wind parks will have larger profits under the new legislation resulting in an increase of the NPVs at least by 6%.

Wind development in the country has been remarkable, and Portugal has achieved a reduction in 22 million metric tons of CO_2 emissions, and a reduction of its fossil-fuel based electricity generation from 80% to roughly 50%, mainly because of wind. Nonetheless, it is extremely urgent to put into perspective the design of the policy mechanisms that are currently providing large benefits to wind producers and financed by all Portuguese consumers.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2014.06.013.

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