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Lessons from wind policy in Portugal

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A R T I C L E I N F O

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A B S T R A C T

Wind capacity and generation grew rapidly in several European countries, such as Portugal. Wind power adoption in Portugal began in the early 2000s, incentivized by a continuous feed-in tariff policy mechanism, coupled with public tenders for connection licenses in 2001, 2002, and 2005. These policies led to an enormous success in terms of having a large share of renewables providing electricity services: wind alone accounts today for ~23.5% of electricity demand in Portugal. We explain the reasons wind power became a key part of Portugal's strategy to comply with European Commission climate and energy goals, and provide a detailed review of the wind feed-in tariff mechanism. We describe the actors involved in wind power production growth. We estimate the environmental and energy dependency gains achieved through wind power generation, and highlight the correlation between wind electricity generation and electricity exports. Finally, we compare the Portuguese wind policies with others countries' policy designs and discuss the relevance of a feed-in tariff reform for subsequent wind power additions.

1. Introduction

Concerns over climate change and environmental effects, energy security, and demand growth have led several countries to set goals for increasing the share of endogenous renewable energy sources in their electricity grid. Renewable energy, though still representing a very small fraction of the energy sources used globally, continues to increase rapidly, with a 32-fold increase between 1980 and 2011 (WB, 2014). Together, all renewables represent about a quarter of total global power capacity installed (EIA, 2014), with non-hydro renewable power increasing at a faster pace than hydro capacity during this last decade. From these new capacity additions, about 60% are wind parks.

These increasing trends in renewable power are taking place in many countries around the world, and these are critically needed as part of a portfolio of strategies to move the world towards low carbon, sustainable, affordable and environmentally just energy system. In 2015, the U.S. alone installed more wind power capacity than capacity from any other technology (EIA, 2016). In the E.U., renewables accounted for 77% of new power capacity (REN21 2016) with 7 GW (SolarPower Europe 2016a,b) and 13 GW (WindEurope, 2016) of solar and wind power additions, respectively.

Portugal was one of the countries with an impressive increase in wind capacity additions and generation. Today, Portugal's cumulative wind power capacity is approximately 5040 MW (DGEG, 2016). Wind diffusion in Portugal started in the early 2000's – consistent with the global trend. By then, less than 1% of Portugal electricity production came from wind sources. Today, wind accounts for more than 23% (REN, 2016) of total electricity generation in the country, and wind power has become the second largest contributor to renewable electricity production in the country, after hydropower. The nation aims to meet a renewables target set by the European Union to attain 5300 MW of cumulative wind power capacity by 2020 (Diário da República, 2013b).

The large share of wind in Portuguese electricity production is a consequence of both European Union (EU) mandates and national policies, as others in the technological innovation and policy literature have well documented (Ferreira et al., 2007). The questions that arise, in turn, are whether this was an effective strategy and policy for Portugal, and how much this costs the Portuguese ratepayers. What were the benefits and the costs of the Portuguese wind policies, and did the benefits outweigh the costs? In this paper, we review the motivation behind the deployment of wind power in Portugal, the policies that have incentivized wind power investments, and some of the consequences of high wind power penetration in the electricity sector. In the

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next sections, we explain the reasons wind power became a key part of Portugal's strategy to comply with European Commission climate and energy goals (Section 2), provide a detailed review of the wind feed-in tariff mechanism (Section 3), and we describe wind policies in a few other countries (Section 4). We describe the actors involved in wind power production growth (Section 5). We estimate the environmental and energy dependency gains achieved through wind power generation, and highlight the correlation between wind electricity generation and electricity exports (Section 6). Finally, we discuss the relevance of a feed-in tariff reform for subsequent wind power additions (Section 7).

2. Policy drivers for wind diffusion

In 1998, the European Community signed the Kyoto protocol, which established a goal for Europe, as a whole, of a reduction of greenhouse gases in 8% from 2008 to 2012 when compared to 1990 emissions levels. This overall European goal was then translated to specific goals for each member state (2002/358/EC), and each member state ratified their mechanisms of action by June 2002 (E.U. Council, 2002).

There were several documents by the then European Economic Commission (EEC) regarding the importance of renewables and overall climate change goals for the Europe[3] since as early as 1986.

On the renewables front, it was only in 2001 that the European Commission (EC) issued the Directive 2001/77/EC, which established a European Union (EU) goal of having 12% of gross domestic energy consumption from renewable energy sources (RES) and 22.1% of gross electricity consumption from RES by 2010 (EC, 2001). Portugal committed to produce 39% of its electricity from all renewable energy sources by 2010. With an already large renewable base, dominated by hydropower plants, this goal seemed reasonably attainable. A national roadmap goal was established (E4 Program), which included increasing the total electricity generating capacity of renewables from 4600 MW in 2001 to 8800 MW in 2010 (Ministério da Economia, 2001). Wind power was therefore chosen as the technology and energy source to develop in pursuit of the country's renewable energy targets, and a goal was set to increase wind capacity from 80 MW in 2001 to 3300 MW in 2010 (Ministério da Economia, 2001). This process has been also documented by Ferreira et al. (2007) and Bento and Fontes (2015).

On the climate change and greenhouse gas emissions front, the EU directives established that the country could increase its emissions by 27% between 2008 and 2012 (i.e. it has a net emission allowance), when compared to 1990 levels. This allowance was provided on the grounds of economic growth, which was deemed necessary to move Portugal closer to the economic and development levels of other EU member countries. Targets were set and ratified in the late 90 s at the EU level, and in the early 2000s in individual member states. Over the course of the early 2000s, Portugal published its national energy plan under the E4 Program, issuing a "National Program for Climate Change," which provided guidance for years 2004–2006. This plan emphasized renewable energy, efficiency, and transport measures in the energy sector, which accounted for more than 70% of total CO_2 emissions in 2004 (Ministério do Ambiente, 2006). The goal for renewable energy sources under the climate change program was set in alignment with the existing E4 Program.

By 2007, as a result of on-going EU discussions about an EU-wide Climate and Energy Package, renewable energy goals were ambitiously raised: 45% of EU electricity would be sourced from renewable energy by 2010 (Diário da República 2008). The Climate and Energy Package resulted in a new EU Directive, 2009/28/EC, establishing what has become known as the 20-20-20 goals. This new directive established binding national goals for 2020 to source an overall 20% of EU final energy consumption from renewable sources, a 20% reduction in EU greenhouse gas emissions from 1990 levels, and a 20% improvement in the EU's energy efficiency. By 2010, each member country had to present a national plan to achieve their respective target. The target for Portugal was to produce 31% of the gross final energy consumption from renewable electricity by 2020 (EC, 2009). To be clear, this is indeed a goal for all final energy consumption, not only electricity generation. Portugal established a national renewable energy strategy (NREAP) that required 60% of its electricity to be produced from renewable energy sources in 2020, 24% of that coming from wind, and to have 6.8 GW of wind onshore capacity installed by 2020 (EU Commission, 2010). This is in addition to deriving 10% of energy consumption in the transport sector from renewables. In January 2014, the European Commission communicated (EC, 2014a) that a framework was being developed to generate subsequent goals for the year 2030. The proposed target is to achieve 27% of final energy consumption from renewable energy. The proposed target is supposed to be binding at the EU-level and not at the level of member states. Thus, "the E.U. target would not be translated into national targets, leaving greater flexibility to Member States to meet their [...] targets in the most cost-effective manner" (EC, 2014a).

As Portuguese goals for climate mitigation and renewable generation were established, so were procedures that wind producers had to follow. For example, wind power plants require a connection license or right to connect to the national grid and sell electricity to the utility; these details for grid connection were only established in 2001. Between 1988 and 2001, there were very few wind parks and the connection license process was quite unclear, deterring potential wind investors. By 2001, the connection procedure became more transparent, with detailed procedures established to allocate connection permits for power producers. Changes in 2001 legislation also established that the project developer should cover the extra financial costs that might arise due to grid extensions. The legislation states that the grid operator and the distribution company are responsible for planning the extension or update of the grid, and that all procedures to grant connection rights are public.

As of 2001, there were two procedures for an independent power producer to have a "connection right" to the Portuguese grid: 1) a direct procedure in which parks individually ask for a connection license when the Portuguese Directorate of Energy (DGEG) establishes available connection points; and 2) a public tender in which specific criteria apply to grant connection licenses. The majority of connection licenses in Portugal for wind power generation have been awarded in public tenders opened in three years: in 2001, 2002, and 2005, with 1 GW, 2 GW, and 1.7 GW awarded, respectively. In particular, the 2005's public tender, awarded between 2005 and 2008 to ENEOP (1 GW), Ventinvest (0.5 GW), and 12 different developers (0.2 GW). Wind projects corresponding to more than 10 GW requested a connection license before 2008. Only 4.7 GW received a connection right, and about 80% of these were already connected by December 2010. The remaining 20% were either under construction or awaiting an environmental license by December 2010 (ERSE, 2014; ERSE 2012a; Sá da Costa, 2012).

Even though the many wind parks are connected in the windiest regions (Center and North of the country), and a methodology for identification of sustainable wind potential was in place (Simoes et al., 2009), it may have been that the construction of wind parks was done in sub-optimal sites, as the availability of land for wind developments was limited due to three reasons: 1) land owners were reluctant to provide their land for wind park developments; 2) there were multiple owners for some parcels of land and therefore contracts for land use were extremely onerous and time consuming; and 3) grid connections

[3] A Green and a White Paper were published in 1997. A green paper is a document that invites to discussion and debate on the basis of the proposals they put forward. The Green paper launches a consultation and often leads to White papers, which contain proposals for the community to take action in a specific area. "When a White Paper is favourably received by the Council, it can lead to an action program for the Union in the area concerned." (EUROPA, 2014) These documents presented non-binding renewable energy goals, and preceeded the 2001 EU Directive.

could need to cross several land parcels, depending on the extension of the distribution grid where added complexity to reach agreements between land owners and wind developers (EDP, 2013). Also, substantial network connection expansions were needed, as the grid was mostly developed along coastal load centres. Even in cases where network lines existed, connection capacities restricted the sites available for wind. In addition, there are several environmentally protected areas that could limit the development of infrastructure (INE, 2011), though wind farms can be set up in protected areas, as long as they undergo Environmental Impact Assessment and obtain a favourable decision from planning authorities. The average percentage of protected areas in Portuguese municipalities is about 8.5%, but some municipalities have designated as much as 50% of their area as environmentally protected.

Other aspects related to projects' locations and their economics might have made the location of the wind sites sub-optimal in terms of maximizing electricity generation. When the licensing requirements were published, the vast majority of wind projects were economically viable even in locations with poor wind resources, due to very high wind feed-in tariffs (we describe these in further detail in Section 3). In addition, public tenders dictated that projects had to be submitted in a short time span. There was neither time nor information to assess the trade-offs between increasing electricity production in windier regions and investing in longer and more expensive grid extensions, which could make sense or not depending on the trade-offs between transmission costs and wind resources (Hoppock and Patiño-Echeverri, 2010; Lamy et al., 2014, 2016). For wind power producers, having land licenses in a region close to an existing connection point superseded the need for better wind conditions. For example, in 2002 there were 7 GW of projects that were presented and only 2 GW were granted. This shows that all of these projects were economically attractive due to the high level of the FIT subsidy. In fact, in previous work we show that most of the existing wind parks in Portugal have been over-subsidized (Peña et al., 2014) and that lower levels of FIT would still ensure the return on investment by those independent power producers.

Portugal also aimed to reduce energy dependence[4] from 87–74% in 2020 (EU Commission, 2010). According to the EU Commission (2010), and based on the National Renewable Energy Action Plan presented by Portugal, this would represent €2 to €2.3 billion (using a reference Brent equal to \$80/bbl) in savings between 2010 and 2020. Lastly, Portugal also aimed to consolidate an industrial cluster of wind power, creating 100,000 new jobs by 2020, in addition to the existing 35,000 jobs associated with the production of electricity from renewable energy sources (EU Directive 2009). This cluster includes five companies and four specialized centres that, in conjunction with national and foreign companies, can provide all services for the installation and maintenance of wind parks.

The Resolution of Ministers 20/2013 updated the National Plan for Action for Renewable Energy 2013–2020 (ADENE, 2016), establishing wind power goals that are more conservative than those set in the National Renewable Energy Action Plan submitted to the European Commission after the Renewable Energy Directive 2009/28/EC. The wind target established in the most recent version (of 2012) of the National Renewable Energy Action Plan (EC, 2016) is 6.8 GW of onshore wind attained by 2020. Energy planning reports by the Transmission Grid Operator (REN) and the Directorate of Energy (DGEG) consider the lower wind targets established in the Resolution of Ministers, 5.3 GW and 6.4 GW of onshore wind by 2020 and by 2030, respectively (Ministério da economia e do emprego, DGEG, and REN, 2013; Diário da República 2013b). These are the targets that we consider to be in place.

[4] According to the Directorate of Energy of Portugal, energy dependence is based on primary energy consumption and imports, and equal to: (Imports-Exports) /(Energy Consumption + International Navy + International Travel) (DGEG, 2014).

3. Policy mechanisms established by Portuguese law: feed-in tariffs

While the EU requires overall renewable goals for each individual member state, each member has the flexibility to select a mix of energy technologies, sources, policy mechanisms, and instruments necessary to achieve these goals. Countries have pursued a variety of mechanisms such as price or quantity-based policies (Van Dijk et al., 2003) (see Table 1 for an example of different mechanisms pursued by different countries). Price-based policies include FITs and quantity-based mechanisms include renewable portfolio standards (RPS) and bidding systems. In Table 1, we outline the different mechanisms currently being used by different European countries, and in Section 5 we discuss the current status and trends for a few countries.

Portugal has relied on feed-in tariffs as the key mechanism for wind diffusion. The electricity commercial agent Electricidade de Portugal Serviço Universal (EDP SU) is required to purchase power from wind independent power producers (IPPs) at a rate estimated each month for each wind park. Even though Europe is known for its promotion of renewable power through feed-in tariffs, the design, period, and level of the feed-in tariffs differ greatly across countries. In Fig. 1, we illustrate the changes in the FIT in Portugal over time, the changes in other countries, along with the major E.U. Directives that set the main framework for renewable energy incentives.

When the period and conditions are compared across countries, the Portuguese FIT for existing onshore wind parks is deemed particularly generous. Other countries, such as Germany and Italy, are now transitioning from electricity production based incentives to market integration incentives, such as flexible premiums and management bonuses. These are incentives granted on top of the market price, to grant financial certainty to the investor at the same time that renewables are directly incorporated in the electricity spot market. Instead, Portugal has continued to pursue a strategy that relies on feed-in tariffs. For example, as recently as in 2013, a new law ratifies the feed-in tariffs as the key policy instrument to incentivize wind power (Diário da República, 2013a).

The feed-in tariff scheme in Portugal has been designed from the beginning so as not to impart any financial risk to the wind producer. The feed-in tariffs are paid on a "MWh of electricity produced" basis, and have ranged from \$85 to \$180/MWh (\$2005) over the last 20 years (ERSE, 2014). Since 2001, the average national feed-in tariff has remained relatively constant around \$103/MWh. Currently, the tariff is guaranteed for 20 years of production or until the site reaches 44 GWh of electricity generation per MW installed (Diário da República, 2013a).

The current FIT scheme design is a result of a long history of incentives. As early as 1988, Portugal had implemented the first FIT incentive. Between 1988 and 2001, the FIT value was technology and source neutral, i.e., all sources of electricity generation received the same FIT amount per MWh produced. Also, until 2001, there was no specific procedure for applying for connection licenses to the grid. Since its inception in 1988, FIT payments to power producers are defined in Portuguese law according to a formula that is computed for each power producer, for each month.

There have been changes to the equation used to compute FIT incentives, and to the period of remuneration, in 1999, 2001, 2005, and 2013. A key transition in 1999 was that the tariff paid to a wind producer was defined as the sum of three factors –fixed (*PF*), variable (*PV*), and environmental (*PA*). In addition to those, in 2001, a factor for technology differentiation (*Z*) was introduced. The current tariff is computed as:

$$Payment_m = T \times [PF + PV_m + (PA \times Z)] \times inflation \times trans \quad (1)$$

In Eq. (1), *Payment* (in euros) is the payment to the power producer in month *m*; *PF* is a fixed value independent of the electricity generated (in euros). *PV* is a variable portion of the payment, which is a function of how much power is generated by the wind park in month *m*,

Table 1
Renewable energy support policies in some E.U. countries.

	Feed-in Tariffs or Premium Payment	Electric Utility Quota Obligation or Renewable Portfolio Standard	Net Metering	Tradable Renewable Energy Certificates	Tenders
Austria		X		X	
Denmark	X		X	X	X
France	X			X	X
Germany	X				
Italy	X	X	X	X	X
Portugal	X	X			X
Spain			X	X	
Switzerland	X				

Based on REN21 2014 report (REN21 2014).

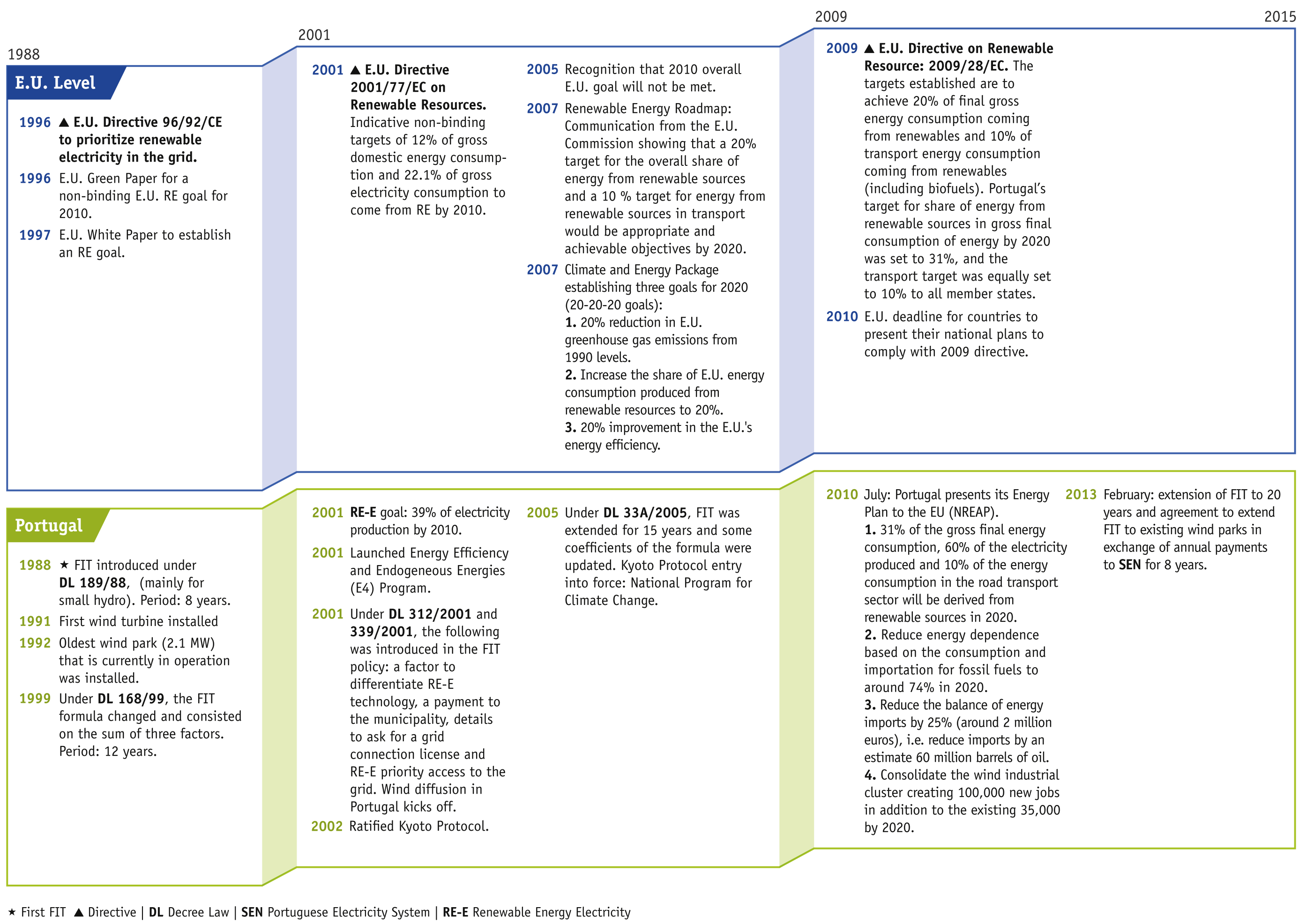

Fig. 1. Timeline highlighting the adoption of feed-in tariffs in Portugal and other regions of the world. Figure constructed by the author and based in multiple sources. More details in Supplemental information (Mendonça 2007, 2009; Couture and Gagnon, 2010; Deutsche Bank Research, 2012; Lang and Mutschler, 2012; EC, 2013; Diário da República 1988; Diário da República 2013a; Diário da República 2001; Diário da República 2005; Diário da República 1999).

and *PA* is a constant environmental factor (in euros), which accounts for the fact that renewables contribute to a decrease in the environmental and health damages associated with fossil fuel generation. *Z* is a factor that takes different values for different renewable energy sources and technologies, and *T* is a factor that accounts for the time of day electricity is produced (non-dimensional). *Inflation* and *trans* correspond to inflation adjustment (non-dimensional) and avoided electricity transportation and distribution costs arising from the use of wind power at local level (non-dimensional). In the Supplemental Information (SI), we show the values of each factor according to the main decree-laws in Portuguese legislation and in Fig. 2 we show the nationally averaged tariff per MWh paid for each of the seven renewable energy technologies from 2000 to 2010.

One of the questions that arises as one considers the effectiveness of the FIT levels as designed is whether these levels were needed for independent power producers to be able to recover the costs. Peña et al. (2014) have estimated the profits from wind independent power producers for wind parks that were connected in Portugal between 1992 and 2010, by connection year. In that work, they concluded that the feed-in tariffs have overcompensated some wind power producers, and that the same level of wind adoption could have been achieved at a much lower level of incentive.

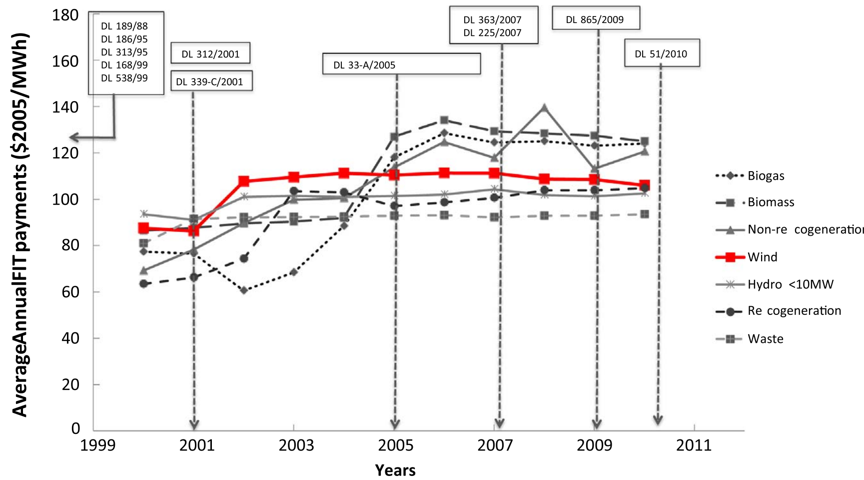

Fig. 2. Average annual feed-in tariff payments in Portugal from 2000 to 2010 for several renewable energy technologies and sources. The text boxes labelled as D.L. stand for key changes in the renewable remuneration over time and are summarized in the Supplemental Information. Solar FIT is not shown due to its large difference compared with the rest of technologies: national average solar FIT was $710/MWh, $680/MWh and $380/MWh in 2003, 2005 and 2010 respectively (solar capacity installed appeared in 2003 in Portugal). Data from (ERSE, 2012a). Conversion to dollar assumes $1.24 dollar/euro.

Using information on total wind generation by region and year from public data sources (ERSE, 2012a; DGEG, 2014), and applying the detailed formulas and factors included in each of the decree-laws issued by Portugal since 1988, we have computed our own estimate of the total annual spending in wind tariff payments from years 2000–2010 to identify the corresponding share by each factor of the formula. We compare such estimates with the actual reported payments as listed in (ERSE, 2014) and present them in Fig. 3. Annual payments grew over time, reaching an impressive cumulative of $1 billion by 2010. In comparison, Portuguese GDP in 2010 was $234 billion.

Our estimates are lower than the official reported values. The discrepancy between our estimated values and the actual payments is likely to be due to the *T* and *trans* factors – factors that correspond to the time of day at which electricity was produced and the avoided transmission costs, respectively. In our estimates, we used the average of the limits imposed in the legislation.

The most recent numbers report that out of the 499 wind farms installed today in Portugal, all but 5 remain in operation (INEGI, 2016) with a few of the existing parks having operated for more than 20 years. All wind parks currently in operation have received tariffs since they first connected to the grid, and older parks, which were connected in 1992 and 1993, are expected to keep receiving it at least until December 2019. The newest wind parks will receive the tariff until December 2036 (Diário da República, 2013a). Efforts to alter the level of wind power remuneration downwards have not been successful: at the end of 2013, a proposal to apply a production tax to renewable producers encountered severe objections. To the extent of our knowledge, Portugal has provided FIT to wind power producers for 20 years, a longer period of time than any other country, with no policy instruments that transfer any market risk to the developer. Moreover, it is the country with the longest FIT period that already has a mature wind power sector. The Portuguese wind support policy needs to be revised to account for the maturity of wind technology, as is the case in many other EU countries.

4. Mechanisms to support wind adoption in other countries

Other countries had substantively different feed-in or other incentive schemes. For example, Germany's feed-in tariff included a digression rate from its inception: it incorporated reductions in the FIT as wind technology matured and became less expensive. Currently, the onshore wind FIT in Germany is $111/MWh for the first five years and

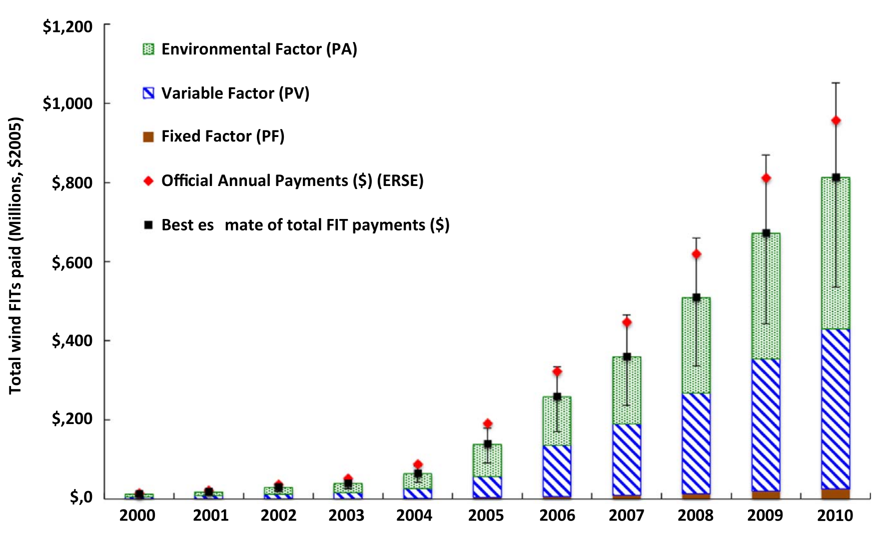

Fig. 3. Authors' estimates of total wind tariff payments to wind power producers, and actual reported payments from 2000 to 2010. Error bars correspond to high and low limits in the coefficients in the FIT equation corresponding to hour of wind generation and transmission and distribution avoided costs.

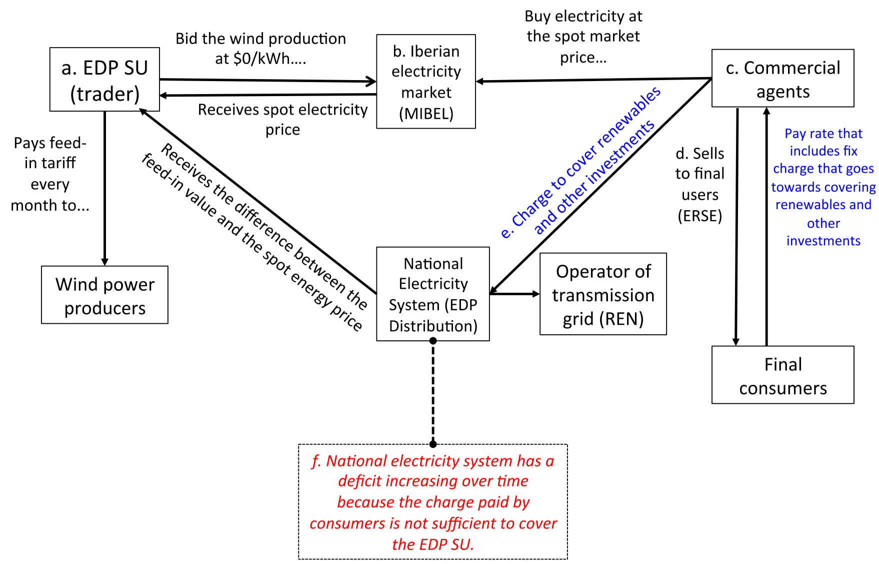

Fig. 4. Actors in the wind FIT scheme in Portugal.

\$60/MWh for the next 15 years, with an annual digression of 1.5% from the year of connection. In January 2012, Germany included a premium mechanism, where instead of receiving the feed-in tariffs, power producers bid directly into the energy market and a premium is provided to the producer on top of that amount. The remuneration per kWh purchased by the grid is the same under the premium mechanism as it is under the FIT. The difference is that the premium required wind producers to enter the market directly, or to establish a contract with a third party to sell their electricity (Brown, 2013). Similarly, in Denmark, the current incentive relies on a market premium with a cap. The cap for wind parks financed by utilities is equal to \$50/MWh, and the premium is given for 10 years (EC, 2013). Currently, a wind park in Portugal is receiving a subsidy approximately twice the size it would receive in Denmark (ERSE, 2014), and it does this risk-free because it never competes directly in the market (REN, 2013a).

In Italy, wind parks larger than 5 MW are awarded a connection license based on reverse auctions, i.e., those that bid the lower feed-in tariff. In Spain, as a result of a financial deficit associated with renewable incentives, the feed-in tariff was phased out for new projects starting in January 2012. Also since 2012, existing projects have faced retroactive cuts, which include the following: 1) power producers have a limited number of hours for which they can receive a special remuneration; 2) the inflation adjustment is set to lower levels; 3) power producers have to pay a grid access fee; and 4) lifetime support has been eliminated (Brown, 2013). The retroactive cuts were designed in order to guarantee a maximum return on investment of 7.5%.

In the U.S., there are federal and state incentives for renewable power. At the federal level, there are investment grants and, until recently, production tax credits (PTCs). PTCs are credits over corporate taxes, usually given for a period of 10 years, and approximately equal to \$22/MWh (DSIRE, 2011). The PTC was perceived as a critical incentive and expired in January 2014. The PTC had a recent five-year extension and phase-out under the Omnibus Appropriations Bill (2015). At the state level, Renewable Portfolio Standards (RPS) established specific goals for renewables penetration in the electricity generation mix by a specific target date. Currently, 30 states and the District of Columbia have RPSs (Barbose, 2012; EIA, 2012) and require or use renewable energy credits (RECs). RECs are tradable certificates that represent the attributes of electricity generated from renewable sources and are used to demonstrate RPS compliance (Holt and Lori, 2005). Wind projects can also pursue Power Purchase Agreements (PPAs), where an established price is set for periods ranging between 15 and 25 years.

5. Key players in the Portuguese wind development

In Portugal, the grid must take wind generation. The main intermediary is *Electricidade de Portugal Serviço Universal*, or EDP SU. The trading agent buys electricity from the wind power producers and other renewable electricity generators, and, in return, pays these renewable power producers the feed-in tariff value. Other commercial actors buy electricity from the traditional power generators through Power Purchase Agreements (PPAs or CAEs in Portuguese), Maintenance Equilibrium Contracts (MECs or CMECs in Portuguese), or directly in the market (Quejas Machado Gil 2010). All of the electricity trade goes to the Spanish and Portuguese electricity market pool (MIBEL), which includes renewable and non-renewable sources, and is traded across commercial actors, such as EDPSU, AUDAX, GNEL, and UFCO. The feed-in tariff is provided to all wind power producers. The tariff is funded, in part, through the redistribution of its costs across all electricity consumers. Three key players, ENEOP2, EDP Renováveis, and Iberwind account for 45% of the total installed wind capacity. The majority of developers are multinational companies and major Portuguese and foreign economic groups with activities in other environmental sectors. For instance, the largest energy operator in the country, Energy of Portugal (Energias de Portugal, EDP), has eight subsidiaries, encompassing electricity distribution, national gas electricity generation, and renewable power companies. It also directly owns 39 wind parks and another 21 parks through ENEOP2, accounting approximately for 600 MW (EDP renováveis 2012).

Fig. 4 shows a diagram with all the actors involved in the wind FIT mechanism in Portugal. EDP SU is the trader agent that is required to buy all electricity from wind producers (and all other renewable power producers) at the feed-in tariff rate (see (a) in Fig. 4). EDP SU then trades it in the Iberian Electricity Market (see (b) in Fig. 4). The numerous commercial agents that operate directly in the market sell the electricity to other commercial agents or to final consumers at different rates under liberalized contracts that still include regulated tariffs (see (c) in Fig. 4). There are 11 commercial agents (CUR in Portuguese) and EDP SU is the largest. Thus, EDP SU operates both as a buyer and a seller of wind power, as well as a commercial agent under contract with final consumers. The rate to consumers offered by last resource commercial agents includes an energy tariff, a distribution and transmission tariff, a “global use of the system” tariff, and a commercialization tariff (d) (ERSE, 2012b). The payment to support renewables is included in the “global use of the system” portion of the tariff (e). This payment to support renewables is not applied equally to all consumers: it is differentiated according to the voltage level of the connection, and is lower to consumers at high voltage levels (i.e. industries and large consumption points, such as trains and other public services).

Over time, a financial deficit accumulated to the Portuguese electricity sector, due in part to the poor design of the feed-in tariff scheme (see (f) in Fig. 4). The energy trading agents (EDP SU) sell energy in the market below the feed-in tariff value. In general, all electricity coming from wind power represents a net economic cost to the electricity system (SEN), since the spot electricity market price at which wind electricity is traded is lower than the feed-in tariff paid to wind power producers. On average, the net economic cost associated with this difference is about $40 per MWh. Part of this difference is shouldered by the ratepayers. However, the amount charged to the ratepayers has generally been below the needed amount required to fully support the difference between the feed-in tariffs value and the market price. This strategy has been generally justified as a way to avoid high end-use electricity rates to ratepayers. This accrued deficit contributes to the general electricity system (SEN) deficit.

The total financial deficit of the electricity system – including the deficit attributed to renewable incentives, purchasing power agreements, and subsidies to fossil generation – is currently in the range of $2.5 billion.[5] Since May 2011, mechanisms have been put in place to reduce the deficit, and are overseen by the European Commission, the European Central Bank, and the IMF. These mechanisms include restructuring the feed-in tariff scheme (EC 2014b). In the last assessment of the Portuguese Assistance Program, the EU Commission lists "reform packages aimed at reducing excessive rents and cutting the electricity tariff debt" as a key structural reform to be made to the energy market (EU Commission, 2014). In the eleventh review of the Portugal Program in April 2014, a target of eliminating the tariff-debt by 2020 was considered, which assumes an increase in electricity prices of about 2% per year. In addition, other measures are anticipated from Portuguese Authorities (EC 2014b).

As part of the tariff-debt reduction program, Portugal re-designed its feed-in tariff policy. In February 2013, Portugal established that wind producers should pay approximately $7000/MW-installed per year to the electricity system between 2013 and 2020 (Diário da República 2013a), in exchange for a feed-in tariff period extension of 5 or 7 years. This reform does not represent a net reduction in FITs, but instead it defers the costs to the future. Irrespective of the mechanism implemented to cover the electricity system deficit, it is likely that electricity consumers will ultimately bear these costs.

When accounting for consumer power parity, the Portuguese residential electricity rates are the third highest across the 28 members states of the European Union (EU 28) with an average residential electricity rate of 0.26 euros[6]/kWh in 2013. If taxes are excluded, Portugal drops to the 16th position, given that taxes and levies –which include the support for renewable feed-in tariffs – account for more than 40% of the total electricity tariff (EC 2014c). There is fierce debate in Portugal about high electricity prices and poor feed-in tariff design. In March 2013, the Secretary of State for Energy resigned from office shortly after he exposed a potential increase in residential electricity prices and urged a public debate on feed-in tariffs. Without a clear and open debate, it is likely that the costs associated with the feed-in tariff will keep increasing the electricity deficit still.

[5] Estimates of the deficit range from 1750 million to 1800 million euros. Assumed exchange rate: 0.72 euros/dollar.

[6] Eurostat reports these values in PPS/kWh, where PPS corresponds to euros after normalized by the power purchase parity of each country of the EU28.

6. Effects of wind power: avoiding potential unintended consequences

6.1. Implications of high renewable resources

While wind developments in Portugal come with tremendous benefits, potential unintended consequences should also be considered. One potential unintended consequence in the future is that consumers may bear the cost of FITs that are used to export electricity to Spain. To better understand this effect, consider the first three months of 2013, when hydro production was four times higher than over the same period in 2012, meeting 31% of demand. During that period hydro storage was used at 0.88 of full capacity. Wind power provided 28% of total demand and all other renewables (but solar PV) had better conditions than in 2012. The result was that thermal production was at its all-time low since 1996, and there were 6% of net exports to Spain. The FIT for wind is paid to wind power producers in Portugal whether or not the wind generation is used in the country or simply leads to exports given exceed total generation. In this case, the under-utilization of existing fossil power plants and the lower price received for exports compared to the FIT paid for generation resulted in net costs to the Portuguese Electricity System (SEN).

The national energy plans call for more natural gas, more cogeneration, and more renewable power capacity – including 4 GW of reversible hydropower and 2 GW of wind power – and phasing out the remaining two coal power plants. The grid connection capacity with Spain is currently 1600 MW to 2000 MW and is expected to be reinforced up to 3000 MW (DGEG and REN, 2013). In order to understand the total additional renewable energy expected and the likelihood of unintended increasing exports to Spain, we perform a simple scenario analysis for year 2030. We assume that Portugal achieves the capacity goals of 6.8 GW, with the overall total installed capacity in 2030 as shown in Table 2. We assume the two existing coal power plants are phased out as anticipated in the National Plans. We further assume that demand will be stable and with similar load profiles in 2030 as to what was observed in 2012 (a reasonable assumption since demand is not growing[7]). We assume that wind, solar and hydro resources are "must-take" by the grid. We use detailed data from de National Transmission Grid Operator (REN, 2016) that has 15-min generation by source for four representative weeks in 2012 and 2013 and scale that generation profile to the existing capacity in 2030 for all generation. After an extensive statistical analysis of the weeks of 2012 and 2013, we selected two weeks, one with simultaneous high wind and hydro resource, and one with traditional wind and hydro resource. These weeks represent two scenarios:

Scenario A: The week of March 27th - April 2nd, 2013 presented simultaneously a hydro index[8] of 1.90 and a wind index of 1.66 (both correspond to the highest values observed since 1970). During one day of the week, wind and hydro attained simultaneously 0.88 and 0.74 of full capacity use, and approximately 180,000 MWh were exported to Spain –equivalent to half of total wind power generation. If Portugal meets its 2030 goals for wind and other power technologies –including pumped-hydro storage, in weeks with comparable weather conditions there will be about 770,000 MWh of exports to Spain, equivalent to approximately 90% of all power generation that receive the FIT (i.e. wind, solar PV, renewable thermal, and small hydro). Thus, in such an

[7] Power demand decreased: by 0.7% in 2014, compared to 2013; by 2.9% in 2012 compared to 2011; by 3.2% in 2011 compared to 2010 (REN, 2016). The reference forecast documents (Ministério da economia e do emprego, DGEG, and REN, 2013) include an upper bound of 1.4% increase of power demand from 2012 to 2030.

[8] Wind and hydro index are a measure that compares the historical available resource with the current resource, over a specific period –usually weekly or monthly based. An index of 1 means that generation from that resource over a period of time is equal to the historical average over the same period. Incidentally, the values for hydro and wind were observed in the same week. The National Transmission Grid Operator (REN) reports these indexes.

Table 2
Total installed capacity by source in 2030.

	2012	2030
Large Hydro	5239	9650
Small Hydro (> 10 MW)	417	620
Wind	4194	6400
PV Solar	220	640
Thermal Special	1779	2660
Natural Gas	3829	4605
Coal	1765	0
Oil	1111	0

Table 3
Weekly exports for two scenarios in 2030.

	Indexes	Exports to Spain (MWh)
Scenario A	Wind: 0.9 Hydro: 0.94	100,000
Scenario B	Wind: 1.66 Hydro: 1.9	768,700

extreme case, Portugal would be subsidizing power consumers in Spain bearing the cost of the FITs.

In fact, recently, all renewables (i.e. wind, solar PV, renewable thermal, large and small hydro) accounted for 91–166% of power demand between May 7th and May 11th, 2016, with a peak of wind contribution of 92% of power demand and a peak of exports of 34% of total net generation (generation minus pumping) on May 9th, 2016 at 6.00 am (REN, 2016). During those five days, Portugal exported to Spain 615,000 MWh.

Scenario B: During the week of December 17th – 23rd 2012, hydro and wind presented simultaneously indexes very close to 1. Under these traditional weather conditions, the weekly excess generation exported to Spain in 2030 would be approximately 100,000 MWh or 8% of total generation, which is comparable with the current interchanges across the border.

We assume that the wind and hydro resource conditions are independent – a fair assumption as correlation was about 0.14 between 2007 and 2013. Table 3 shows the indexes and total excess generation that is exported for both weeks. Fig. 5 provides the detailed 15-min generation for the week with high wind and high hydro resources.

6.2. *Correlation between market prices and wind penetration*

Unsurprisingly, there is an important negative correlation between

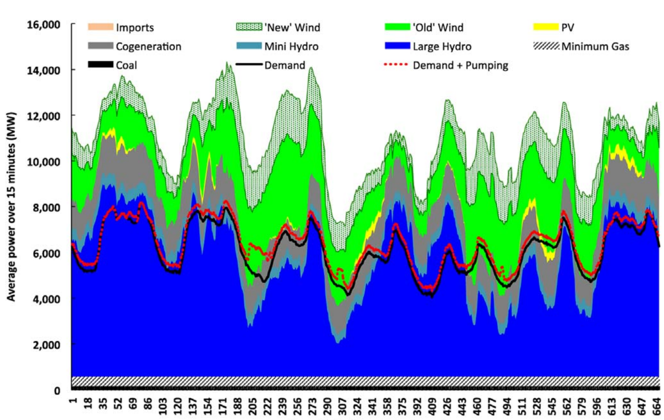

Fig. 5. Hypothetical power profile for Portugal during a week in 2030 with high large hydro and wind output (Scenario A).

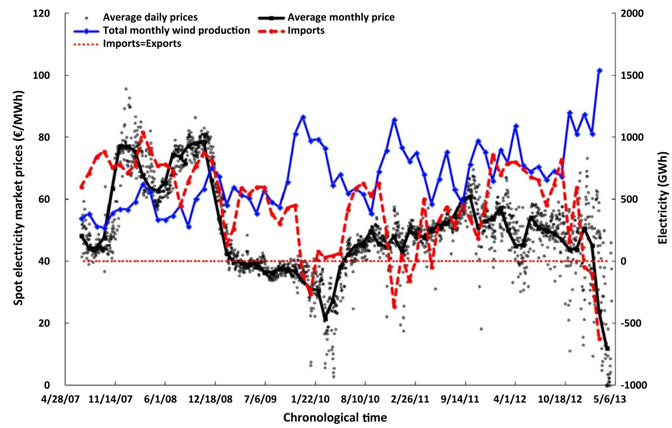

Fig. 6. Average daily and monthly spot electricity market prices, monthly imports and monthly wind generation in Portugal between July 2007 and May 2013. (REN 2013b; OMIP, 2012).

wind production and spot market prices, as wind now competes in the spot electricity market. In Fig. 6, we use data from REN and OMIP to illustrate this effect, using data from 2007 to 2014. Here a correlation of −0.4 is observed between average monthly spot electricity price and total monthly wind generation.

The lowering of spot electricity prices has very important consequences for the national electricity system: currently, wind power producers will receive the difference between the FIT and the spot electricity market price (see Section 5). That difference will obviously be larger when the clearing spot market price is smaller. In turn, this theory would be supported by the Portuguese ratepayers. A portion of this amount is currently being charged to electricity consumers as a share in the electricity rate called 'Support of PRE', and the remainder is passed to the general SEN deficit (see Section 5). Thus, ironically, the share to be covered by SEN and paid to EDP SU per unit of electricity generated, increases when the wind blows the most. Instead, if the wind FIT were to incorporate the market variations – as a variable premium on the top of the market price – the 'Support of PRE' would be constant and smaller than it currently is. This scheme could include a minimum total tariff (market price + premium) for wind parks that have not yet covered their investment costs – those connected after December 2007 (as we show in Peña et al. (2014)) to guarantee a positive return to investment.

But more interesting, this correlation illustrates that while wind power is already incorporated in the Portuguese competitive electricity market, the design of the policy hasn not followed the developments in the market. In fact, EDP SU pays the FIT for all wind generation power producers, and then sells it in the market, bidding at $0/MWh. If wind producers would instead bid in the market directly, they would receive at least the current clearing market price assuming that they will present bids at least of $0/MWh. Thus, the clearing spot market price is expected to be equal or larger than today's. Moreover, existing wind parks, that under the condition of entering the competitive market directly have positive NPVs with the current level of electricity prices, could stop receiving immediately the FIT. This would result in savings of at least $150 million ($2005) per year.[9]

6.3. *The current policy design will likely effectively result in a subsidy to Spanish electricity consumers*

In general, all electricity coming from wind power represents a net economic cost to the Electricity System, because the spot electricity

[9] Assuming all wind parks connected up to December 2007 (approximately 1800MW) have covered their investment costs and enter the spot electricity market. We use 2000h of capacity factor, a FIT of $100/MWh and an average spot market price of $60/MWh ($2005 values).

market price at which wind electricity is traded is lower than the FIT paid to wind IPPs. On average, the net economic cost is about $40/MWh. Nevertheless, this cost has been assumed due to the national energy strategy of lowering energy dependence and CO_2 emissions, and is currently supported through all electricity consumers.

When FIT-supported technologies – and in particular high wind generation – create moments with high exports, the net economic over cost is still $40/MWh,[10] but with part of the consumption being in Spain. Thus, at moments when renewable power generation results in net exports, Portugal will be providing cheap electricity to Spain and covering its high production costs internally.

Thus, on a country level perspective, exports should be reduced at high-generation moments. For example, Portugal can release the condition of feeding all renewables to the grid, and instead allow for spill of wind generation and/or invest in storage technologies. Reducing exports at high-generation moments by spilling power generation is an option that can represent savings as avoided transmission and distribution grid capacity investments.

7. Conclusion and policy implications

Portugal has reduced its fossil-fuel power generation from 64% of total electric power demand in 1994 to about 36% in 2014 (REN, 2016). The ambitious renewable energy goals, and the relatively small expected increase in demand (DGEG and REN, 2013), will likely create a surplus of electricity capacity, and of possible generation. The current national energy plan is to add more natural gas, cogeneration, and renewable power capacity, including 4 GW of reversible hydropower and 2 GW of wind power, and to phase out the remaining two coal power plants by 2017. International trade occurs only through the Iberian Market, which will be limited by the transmission lines connecting Portugal and Spain. A key consideration as wind power grows further is the effect on overall electricity market prices. Numerous factors affect the spot prices in the Iberian market. Portugal guarantees that the grid receives all electricity produced by renewables, which raises the issue of surplus-hours of electricity that would necessitate exports to Spain.

Portugal wind power has successfully grown due to the implementation of a feed-in tariff mechanism. However, the country must now decide how to continue its transition towards low carbon, sustainable electricity systems without egregiously hurting ratepayers, namely in light of a serious recent recession while coupled with high electricity prices when compared to the rest of the European Union.

Portugal has remained stagnant in the way it compensates renewable power generators, and its wind support policy is out-of-date. Wind feed-in tariffs in Portugal do not incorporate any financial risk or digression rate besides inflation, and are guaranteed for every unit of electricity produced. Only five wind sites out of about 500 have ceased operations so far, despite the fact that some wind projects have been in operation for more than 20 years. All wind parks currently in operation have received feed-in tariffs since they were connected to the grid, and they are expected to keep receiving feed-in tariffs until at least December 2019 and up to December 2036. Portugal is the country with the longest feed-in tariff period that already has a mature wind power sector. From the electricity consumer's point of view, the high penetration of wind power increases electricity consumer prices.

We note that while we use wind as the focus of study in this work, many of the points highlighted here will also occur with other technologies and energy sources in Portugal. For example, the fossil generation is also provided with subsidies, and several other renewables (namely solar PV) receive very high FITs. In these cases, only part of the costs of the subsidy are passed through to the rate-payers, with the rest continuing to contribute to a growing financial deficit of the national energy system.

While support to continue the increase in wind and other renewables and low carbon generation in the electricity system is needed, we propose a wind FIT that incorporates the market variations as a variable premium on the top of the market price, and only for wind parks that have not yet covered their investment costs. This strategy would be a more sensible in moving forward.

Portuguese policy makers should be aware of the potential implications of electricity exports at moments of high wind resource, as the price paid for wind generation (i.e. the wind feed-in tariff) is higher than the price received from electricity exports, incurring a net cost for Portugal. A better understanding of those consequences is warranted.

Finally, we note also that the lessons learned here also hold for other countries where subsidies or incentives for renewables are provided while at the same time a transition occurs to liberalized markets. One could foresee scenarios of very high wind generation in Spain leading to exports, in which case Spain would be bearing the costs of the policy incentives to wind, while Portuguese consumers would be benefiting from low spot electricity prices. These sorts of unintended negative consequences really call for concerted international action and planning between market design and energy and climate policy design.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2016.11.033.

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[10] Under the assumption that electricity is exported at the average spot market price.

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