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The Electricity Market Structure in Greece and the Paradox of Renewable Energy Sources

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Abstract

The European Union, in an effort to boost the use of Renewable Energy Sources (RES) in power generation, applies supportive tools consisting in financial motivation either as grants or as subsidies. According to welfare economics, a subsidy should reflect the external benefits; otherwise a distortion of competition takes place. The most widespread method to calculate externalities is the avoided cost approach, despite the fact that it encounters equally all the RES units leading to technological neutrality. In the present article, the avoided cost approach with the objective social justification of RES subsidies/feed in tariffs (FITs) in the case of Greece, for the year 2014, is applied. The results show a high gap between the current FITs and the suggested ones amounting to approximately 40%. This uncomfortable outcome indicates that, at least in the case of Greece, either the level of the current guaranteed tariffs is not socially justified, or the CO_2 value derived from the European carbon market does not reflect the real social cost, or that the avoided cost method, alone, is not adequate to explain the level of subsidies. In light of the foregoing, the need for the development of a concrete and integrated methodology for calculating all RES externalities emerges.

Keywords

Renewable Energy, Feed in Tariff, Avoided Cost, Welfare Economics, Pricing, Externalities

1. Introduction

A first significant step towards establishing a common European strategy regarding the RES promotion was achieved by the adoption of the White Paper on RES (COM (97) 599 final), in November 1997. The reasons for supporting and promoting RES technologies are recorded [1] [2].

In particular:

- The development of renewables is fully consistent to the objective for environmental protection and carbon dioxide (CO_2) emissions reduction in the energy sector.
- Renewables are endogenous energy sources and, therefore, they can contribute to the reduction of imported fossil fuels dependency as well as to the energy supply security improvement.
- The deployment of RES may be conducive to job creation and regional development; leading to greater social and economic cohesion between the regions of the Community.
- The expected energy consumption increase in third countries, which may be covered by RES, provides business opportunities for leading industries in the field of RES located in the EU.

Given that the cost of renewable electricity is higher than the corresponding cost of conventional energy sources, the European Commission (EC) through Communication 2001/C 37/03 defined the forms of state aid which are considered eligible for the promotion of RES. Subsequently, through the Directive 2009/28/EC the need to establish national support mechanisms for the RES promotion was introduced.

The support mechanisms are defined as the legislative schemes being implemented in order to determine the compensation level as well as the compensation procedure of the produced renewable energy. The aforementioned policies may be combined with other measures including network connection priority, dispatch priority, investment grants, and tax incentives [3].

The implementation of support mechanisms aims at developing a business environment within which renewable are able to compete on a level playing field with conventional fuel technologies. This necessity derives both from the insufficient internalization of external social costs into energy prices, as well as from the existence of substantial public subsidies which contributed to the development of conventional and nuclear power plants [4] [5].

The support schemes are divided into three main categories which are either price-based or quantity-based in their approach [6].

- Guaranteed Fixed Price
- Feed-in Tariffs (FIT)
- Feed-in Premiums (FIP)
- Tender Schemes (TS) and/or Competitive Bidding Processes (CBP)
- Tradable Green Certificates (TGC).

The FIT mechanism consists of a fixed and guaranteed compensation per unit of produced energy, providing at the same time long-term sale contracts (usually 20 - 25 years) and therefore maximum investment security. The guaranteed, fixed tariffs may be differentiated depending on the technology used, the size of the power plant and/or the power plant location [7] [8]. Conversely, the FIP system offers a premium above the electricity market spot price. Theoretically, the compensation received by RES producers within the FIP mechanism may be designed in order to serve two objectives: 1) to assess the environmental and/or social benefits of RES electricity production, 2) to value effectively the renewable electricity production cost associating it to the electricity market spot price [9] [10].

Tender Schemes and Bidding Processes are competitive and market-oriented mechanisms based on the production cost of renewable electricity. In TS systems the compensation price of the generated energy is the only criterion which should be evaluated, contrary to the CBP system where additional criteria may be included (e.g. installed capacity, amount of electricity generated, etc.). The support may be in the form of guaranteed fixed or differential prices, while the bidding process may be technologically neutral or relating to a particular RES technology [11] [12].

Within the mechanism of tradable green certificates, the State sets as a requirement for consumers, suppliers or producers, a certain percentage of the electricity that they consume or sell, respectively, to be produced from RES. The RES producers sell their energy to a price equal to the electricity market spot price. They also sell a green certificate which proves the renewable nature of the tradable energy. The suppliers prove their compliance with the mandatory quota by purchasing these green certificates; otherwise, they are subject to penalties [13] [14].

Especially for the guaranteed fixed price mechanisms (FIT, FIP), a pervasive problem during the designing of such a system is the determination of the level of the guaranteed tariff so as to ensure the balance between the investment security and the risk of over-compensation [15] [16]. Even though worldwide [17] a multitude of different methodologies for determining the compensation rates of RES technologies has been recorded, it is useful to differentiate them in two wider categories: 1) methodologies following the cost-based approach and 2) methodologies following the value-based approach [18] [19] [20]. In the first case the calculations are based on the concept of levelized cost of energy (LCOE), taking into account construction cost, operation and maintenance costs, fuel costs, inflation, interest rates, as well as costs related to the licensing procedure. Subsequently, using financial analysis and evaluation tools (annuity method, NPV, IRR) the compensation tariff is estimated so as to lead to reasonable profitability. The aforementioned methodology is being applied in France, Germany, Spain, and Greece [21] [22]. In the second case, the guaranteed price reflects the value of renewable energy from the perspective either of society (e.g. environmental benefits, energy security, employment) or the substituted technology (network losses decrease, avoided costs—external or not) [23]. This value may be estimated through the approach of avoided costs (*i.e.* investment costs, maintenance and operating costs, external benefits and costs of the substituted conventional technology) [24]. A similar approach is being applied in Portugal

[25].

According to the REN21 network [26], during the last two decades the use of support mechanisms as a RES promotion tool has been increased worldwide. In 2014 a total of 138 countries were already applying such mechanisms. In fact, 73 countries and 28 states/regions have adopted the guaranteed fixed price mechanisms (FIT/FIP), while 55 countries define the RES energy compensation rates through tender schemes and/or bidding procedures.

Taking the aforementioned into account and the fact that:

- The international literature mainly deals with the benchmarking of different support mechanisms, as well as with the incorporation of externalities in the process of energy planning and considerably less with the study of renewable energy pricing methods [27] [28].
- The main problem of price regulating mechanisms is the transparent and cost-effective adjustment of the guaranteed tariffs, so as to avoid phenomena such as competition's distortion as well as electricity consumers' burden [15] [29].
- In Greece, during the years 2009-2014, an intense debate was taking place on the methodology applied, regarding the calculation of the RES guaranteed tariffs.

This article aims to present the basic characteristics of the Greek electricity market in the period 2009-2014, focusing on RES sector, as well as to examine, by applying the avoided cost approach, whether the guaranteed tariffs for commercially mature RES technologies (*i.e.* wind, photovoltaics, small hydro) in 2014 were socially justified.

It should be noted that the choice of this time period as well as of these specific technologies is based on the following reasons:

- Between 2009 and 2014, there were installed in Greece 3347 MW of RES stations, of which 74% were photovoltaic stations and the remaining 26% were wind and small hydroelectric plants.
- From 01/01/2016, the RES support mechanism is market-oriented. In that sense there are no longer over-compensation phenomena of commercially mature RES technologies.
- The funding of the RES support mechanism has ceased to have deficits, since 2017.

2. Methodology

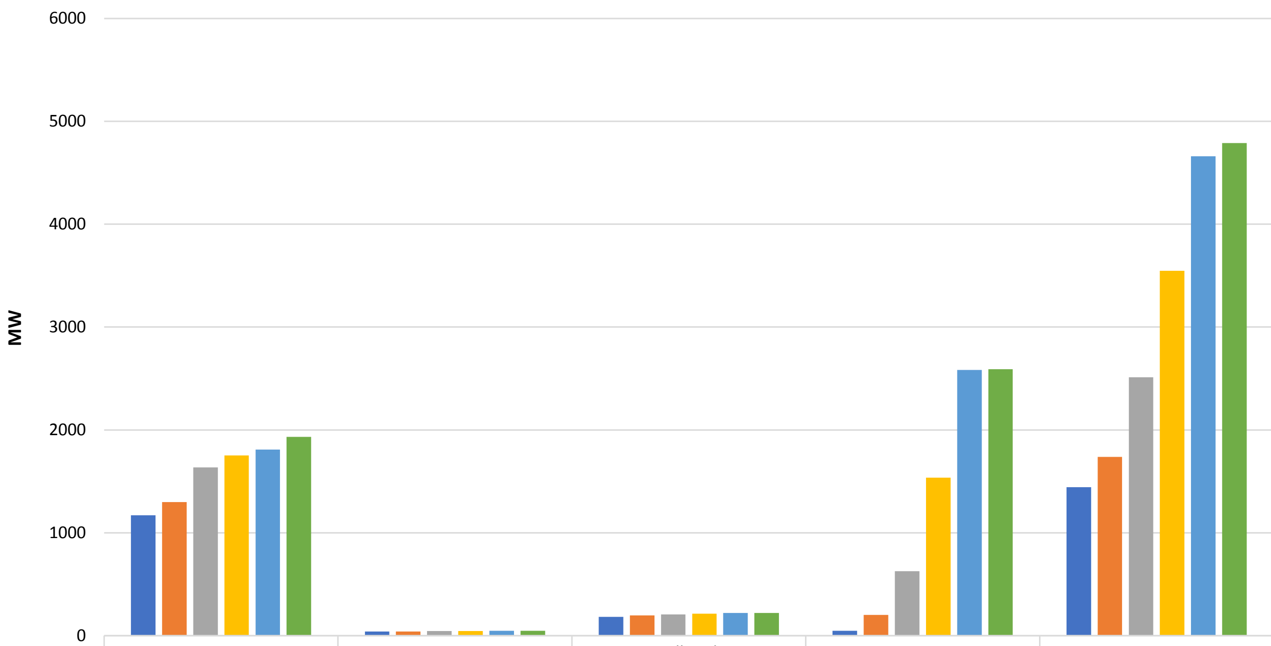
2.1. The Greek Electricity Market

Electricity generation in Greece is based, mainly, on the use of conventional energy sources; domestic lignite and imported gas in the mainland, and oil in the non-interconnected islands). Secondarily, electrical energy is produced by RES. The penetration rate of photovoltaics and wind generators has been increasing during recent years, rendering them the leading renewable technologies in Greece. According to the monthly bulletins of the Independent Power Transmission Operator (IPTO), the electricity consumption in Greece during 2014 was 54.8 TWh with an installed capacity of 11.114 MW in thermal plants and 8.062 MW in RES units. The lignite production accounted for 41.5% of the net production of electricity, the natural gas participated in the electricity energy mix to a percentage of 11.5% while the renewables and large hydro generated 22.6% of power. RES plants' installed capacity evolution from year 2009 to year 2014 is illustrated in Figure 1.

It is worth noting that the total installed capacity of RES technologies in Greece at the end of 2018 was equal to 5828 MW. This means that only 1038 MW have been installed over the last four years, compared with the 3052 MW installed between 2010 and 2014. This reduction in the penetration rate of new RES projects has to do both with the economic crisis and the changes made to the support mechanism from 2015 onwards.

Structure and Function of the Wholesale Electricity Market in Greece in Year 2014

The wholesale electricity market in Greece is a mandatory pool. This market, wherein the producers and the suppliers are bindingly participating, is composed of three main parts [30]: Day-ahead Scheduling (DAS), Daily Imbalances Market (DIM) and Capacity Remuneration Mechanism (CRM).



	WIND	BIOMASS	Small Hydro	PVs	TOTAL
2009	1171	41	183	48	1443
2010	1298	41	197	202	1738
2011	1636	45	206	626	2513
2012	1753	45	213	1536	3547
2013	1810	47	220	2583	4660
2014	1933	47	220	2590	4790

Figure 1. RES installed capacity evolution during years 2009-2014.

In DAS, generation plants are sorted according to their energy offers (which cannot be lower than the minimum variable cost and cannot be higher than an administratively defined price cap of 150 €/MWh). Then, a next-day 24 h production schedule (unit commitment and dispatch) for its plant is determined by taking also into account the submitted load declarations. Both the energy which is scheduled (ex-ante) to be injected into the system by producers and the energy which will be absorbed by the suppliers are transacted at the System Marginal Price (SMP) [30].

In DIM, the actual commitment and dispatch of generation units, the actual absorbed energy from the suppliers, as well as various failures, restrictions, etc. are taken into account. Both the differential energy injected and/or absorbed is transacted at System Imbalance Marginal Price (SIMP) [30].

In CRM, generation plants (thermal power plants and large hydro) are remunerated for their availability and the energy suppliers are charged for the power absorbed by their clients at the annual peak load. This mechanism was established in 2005 for the recovery of fixed costs (mainly investment costs) of conventional plants [31].

2.2. The Greek RES Support Scheme

Under Law 3468/2006, specific and differentiated FITs were set for the various RES technologies. For the case of photovoltaics, significantly high prices were set. Moreover, a provision for a total maximum installed capacity equal to 700 MW was also included in the Law 3468/2006. Tariffs for photovoltaic systems were further defined under Law 3734/2009. This Law included a tariff differentiation with respect to the installed capacity (below and above 100 kW) and location (between photovoltaic systems installed in the interconnected system and in the non-interconnected islands). An automatic tariff digression mechanism for photovoltaics till the end of year 2014 was also enacted. From the year 2015 and onwards photovoltaics' tariff levels are linked with the system marginal price (SMP).

Under Law 3851/2010, new tariffs for all RES technologies and for different sizes, in terms of installed capacity, were defined. The duration of PPA was increased to 25 years for concentrated solar power plants and rooftop photovoltaic systems up to 10 kW and remained at 20 years for all other RES installations. An increase in the guaranteed tariff of wind, small hydropower and geothermal by 20% and of biomass and biogas by 15% was introduced for projects not benefiting from investment subsidies.

Under Law 4252/2014, guaranteed tariffs for all RES technologies, excluding photovoltaic, have been reduced by varying degrees, in order to align them with actual project costs and to avoid overcompensation [32] (**Table A1** in Appendix).

For the sake of completeness, it should be noted that since 2016 the RES support mechanism implemented in Greece has been changed. In particular, the Greek State with the Law 4414/2016 (Official Government Gazette no 149/09.08.2016) adopted a new support scheme of electricity production from RES in order to achieve the gradual integration and participation of new RES plants in the electricity market. This new support scheme foresees a premium in addition to the price at which producers sell the produced electricity directly in the wholesale electricity market. This premium will be guaranteed for the whole period foreseen for operating aid support per RES power plant and will be in the form of a differential value (sliding Feed in Premium-FiP), taking into account the revenues from the participation in the electricity market.

RES Electricity Compensation Mechanism in Greece

Payments for the electricity produced from RES are conducted through a Special Account, which was established in 1999 with specific statutory funds and is managed by the Electricity Market Operator (LAGIE). Given that the guaranteed price for the injected renewable electricity is higher than the marginal production cost of conventional energy, as the previous is defined either by the SMP or the weighted average variable cost of thermal units, this difference is covered directly by the final consumers through a special levy collected through the electricity bills (Special Fee for the Reduction of Greenhouse Gases Emissions—ETMEAR).

The increase in the RES energy production (especially the increase in the photovoltaic's energy production which enjoyed exceptionally high guaranteed tariffs), in combination with the fact that the increase of ETMEAR did not follow the high penetration rate, led to the creation of deficit in the Special Account, which amounted at the end of year 2013 to around 550 mil. € (**Figure 2**). In order to eliminate this deficit, at the end of 2014, a set of structural measures was introduced, aiming at increasing the inflows, and at the same time to reduce the outflows of the Special Account.

It is noted that one of the measures taken was that the inflow to the Special Account from renewable energy sales at the wholesale market should be equal to the product:

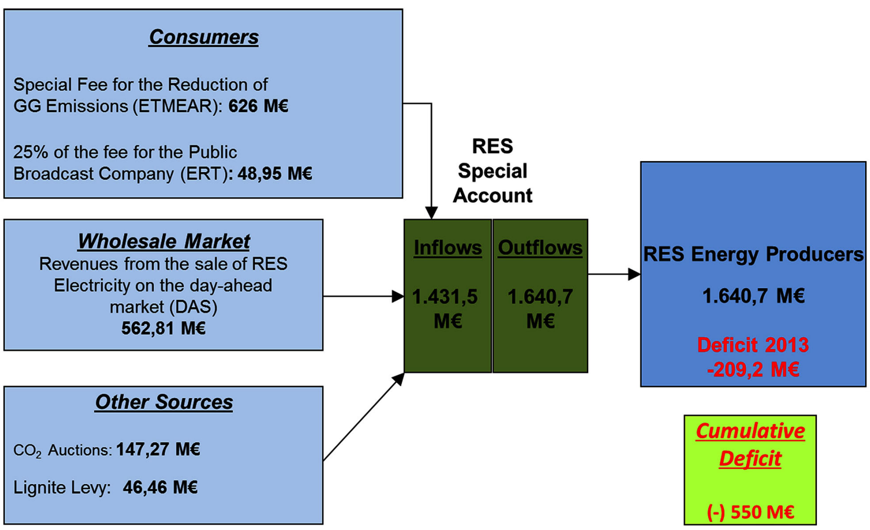


Figure 2. Schematic and numerical representation of the Special Account new inflows (end of year 2013).

$$E_p \cdot \text{WAVCTU} \tag{1}$$

where:

E_p: The energy produced

WAVCTUA: The Weighted Average Variable Cost of Thermal Units

Equation (1) applies only if the hourly algebraic sum of SMP and SIMP is less than the WAVCTU during the corresponding dispatch period.

It should be noted that with the implementation of the structural measures and the change of the RES support scheme, which led—from 2016 onwards—to a reduction of the RES remuneration, the Special Account deficit was zeroed at the end of the year 2017.

2.3. Recalculating RES Guaranteed Tariffs through the Avoided Cost Approach

One of the methodologies for calculating RES guaranteed tariffs, which has been implemented with variations in Portugal and the USA is the approach of avoided costs. According to this approach, the guaranteed price reflects the costs of the substituted conventional technology as well as the benefits arising from the use of RES for the environment and the society. It is argued that the avoided cost should include fixed and variable costs (*i.e.* investment cost, operation and maintenance costs, fuel cost) of the substituted conventional technology [24]. On the contrary, another approach suggests that the avoided cost should comprise the marginal cost of a conventional power plant, meaning the variable operating and maintenance cost [33]. In any case, the methodology in order to be complete should also incorporate the positive externalities resulting from the substitution of fossil fuels by renewable sources.

In 1978 in the United States, under the law PURPA, the public regulated electricity companies, which made use of fossil fuels, were forced to purchase the overall renewable energy produced at prices equal to their own long-term production cost [34]. In the case of Portugal, the algorithm used for calculating the monthly RES compensation tariff includes: 1) the avoided investment cost of a typical conventional power plant; 2) the avoided cost of conventionally produced electricity, namely fixed and variable operating and maintenance cost of a typical fossil fuel unit; 3) the avoided cost of network non-losses due to the decentralized production capability of RES units and; 4) the avoided environmental cost due to non-release of carbon dioxide emissions [25].

2.3.1. Externalities of Electricity Production

According to the neoclassical economic theory, the market mechanism objective is the maximization of productivity, *i.e.* the achievement of greater quantity of the product obtained under the same or fewer production factors [35]. In a "perfect" market the product price is determined by the intersection of supply and demand curves. The demand curve reflects the marginal willingness to pay for the good while the supply curve reflects the marginal production cost. Therefore the equilibrium point, at the price P* and at the quantity Q* is the one for which the following equation applies:

$$\left[\text{marginal production cost of X}\right] = \left[\text{marginal willingness to pay for X}\right] \tag{2}$$

If the marginal cost curve includes all the elements/factors of a commodity's production cost then it is called marginal social cost curve and the price is at the point where the marginal social cost is equal to the demand (marginal willingness to pay) for this commodity (**Figure 3**).

However, in practice, the markets do not function so effectively, especially for free and public goods (social goods). The absence of property rights for environmental and other public goods, combined with the matching of the value of a good to its price (for the majority of the environmental goods their purchase price is zero), result in the creation of external economies (externalities).

An external economy occurs if two conditions are in place [36]: 1) the actions of an economic activity (A) cause a change in the economic welfare of another economic activity (B); and 2) the economic activity B is neither being compensated by the economic activity A (if B economic welfare decreases) nor pays economic activity A (if B economic welfare grows), while B is unable to control or hamper activity A.

Externalities are distinguished in [37]:

- Positive or negative, depending on the direction of prosperity change
- Environmental or not, depending on the type of goods causing the increase or decrease in prosperity
- Pecuniary or technological, depending on the possibility of their transfer in prices
- Constant or variable, depending on the increase or decrease in prosperity which is related to the product volume changes

As it became apparent, the electricity production, like any production activity, is characterized by two cost components: 1) the private cost, which is depicted with the market mechanism and is reflected in the final price of the product, and 2) the external cost, which constitutes the economic expression of this activity's impact to third parties and to society in general and which is not reflected in the final product price. The sum of the private and external cost equals to the social cost of the product [38].

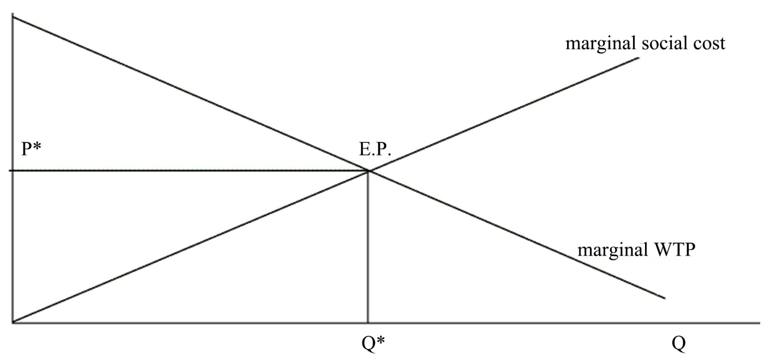


Figure 3. Product price determination under "perfect" market conditions, where P* and Q* are the prices and the quantity of the product at the Equilibrium Point (E.P.) [35].

Environmental externalities of electricity generation plants are related to environmental pressures (air emissions, effluents, waste, and visual pollution) generated during construction and operation of such units and which affect both human health and ecosystems. Respectively, the non-environmental externalities that are caused during electricity generation can be categorized into externalities associated with energy supply security, the depletion of non-renewable natural resources, industrial accidents, the creation of direct and indirect employment [39].

The assessment of environmental externalities that emerged from the first research efforts, which had been conducted during the decade of 1990, proved that for conventional technologies the value of subsequent environmental impacts are particularly critical and their ignorance in the process of energy planning may cause considerable distortions in market operation [40]. Despite the considerable degree of uncertainty surrounding these figures (environmental externalities), it is estimated that they may constitute a realistic assessment base. Typical examples are research programs such as NEEDS and CASES, which were funded by the EU within the ExternE project and which aimed, inter alia, at the deepening of the methodological approach for calculating the environmental externalities, as well as at the assessment of the impact of a potentially internalization of these externalities on the electricity price.

2.3.2. Approach Applied for Calculating Guaranteed Tariffs

The algorithm for calculating the guaranteed tariff of a renewable technology under avoided cost approach can be described with Equation (3).

$$\text{FIT} = \text{AvoidedCost}_{\text{Th.Unit}} + \text{Externalities} \tag{3}$$

where:

FIT: Guaranteed Tariff in €/MWh

$\text{AvoidedCost}_{\text{Th.Unit}}$: Avoided cost of thermal units in €/MWh

Externalities: Positive and/or negative externalities in €/MWh

The first addend of Equation (3) ($\text{AvoidedCost}_{\text{Th.Unit}}$) may reflect either the variable operation and maintenance cost or the total cost of conventional units that are substituted by renewable energy technologies. In particular, in the case that the $\text{AvoidedCost}_{\text{Th.Unit}}$ includes the investment cost, the operation and maintenance cost, and the fuel cost of a typical thermal unit, it occurs on the basis of the assumption that the installation of a RES unit will result in the suspension of a new conventional generation plant construction. Substantially, this approach assumes that the electricity demand is increasing and that its coverage requires the installation of new capacity. In the case of Greece, however, there is an excess of installed power. Moreover, in the Greek energy market, through the CRM, thermal units are able to recover the major part of their fixed costs, especially their investment costs. So, for the Greek case, and in particular for the Interconnected System, the $\text{AvoidedCost}_{\text{Th.Unit}}$ should reflect the operation and maintenance variable cost of lignite and natural gas units.

The second addend of Equation (3) represents the positive and/or negative environmental and other externalities. The environmental externalities are related primarily to the environmental pollution, the climate change and the adverse impacts on human health and ecosystems caused by conventional power plants, due to the release of air pollutants and greenhouse gases. On the other hand, the main non-environmental externalities are related to energy supply issues, mineral resources depletion and employment.

In this article, due to the lack of sufficient data for the assessment of non-environmental externalities, the methodology takes into account and computes only the environmental externalities arising from the replacement of conventional units by renewable technologies, as a result of non-release of SO_2, NO_x, PM, and CO_2. Furthermore, the marginal benefits/costs are calculated. In particular, the calculated benefits/costs relate to the injection of marginal quantities of renewable energy into the electrical system, so as not to affect the operation of the latter. As far as the thermal units avoided cost is concerned, since the methodology is based on the assessment of marginal factors, the former is computed as the weighted average of the variable cost (operating and fuel cost) of the interconnected system thermal plants (lignite and natural gas units), which were operating during the year 2014.

In this context Equation (3) may be amended as:

$$FIT_k = T.W.A.C._{Th.Unit} + T.Env.Ben._k \tag{4}$$

where:

FIT_k: Guaranteed tariff in €/MWh per renewable technology

$T.W.A.C._{Th.Unit}$: Total weighted average variable cost in €/MWh of thermal plants located in the interconnected system

$T.Env.Ben._k$: Total environmental benefit per renewable technology in €/MWh.

The private cost (PC) of a power plant includes: the annual weighted investment cost (IC), the fixed and variable operation and maintenance cost (OMC), the fuel cost (FC) and the purchase cost for greenhouse gas emissions allowances (CC) [41]. The previous costs differ depending on the technology and may be expressed in €/MWh, according to Equation (5).

$$PC_i = \frac{\left(IC_i + OMC_i + FC_i + CC_i\right)}{E_i} \tag{5}$$

where:

PC_i: Private cost of thermal unit i in €

IC_i: Annual weighted investment cost of thermal unit i in €

OMC_i: Operation and maintenance cost of thermal unit i in €

FC_i: Fuel cost of thermal unit i in €

CC_i: Purchase cost of CO_2 allowances for thermal unit i in €

E_i: Annually produced energy of thermal unit i in MWh

The annual weighted investment cost of a thermal unit is calculated through Equation (6).

$$IC_i = TC_i \frac{r}{1-(1+r)^{-N}} \tag{6}$$

where:

TC_i: Investment cost

r: Discount rate

N: energy unit lifetime

The maintenance and operation costs depend on the technology as well as on the age of the unit. They are distinguished into fixed costs ($FOMC_i$) (e.g. insurance, wages, etc.) and variable costs ($VOMC_i$) (e.g. fuel storage, repairs). The fuel cost is usually a distinct part of the variable costs and depends on the technology, the fuel type and the efficiency of the unit (Equation (7)).

$$FC_i = E_i \cdot H.R._i \cdot \frac{FP_j}{Av.LHV_j} \tag{7}$$

where:

FC_i: Fuel cost of the thermal unit i in €

$H.R._i$: Heat rate of thermal unit i in GJ/MWh

FP_j: Fuel price in €/tn for lignite and in €/Nm^3 for natural gas

$Av.LHV_j$: Fuel Lower Heating Value in kcal/kg and kcal/Nm^3 for lignite and natural gas respectively

E_i: Annually produced energy of the thermal unit i in MWh

The purchase cost of greenhouse gas emissions allowances depends on the generation plant technology, the fuel type as well as on the CO_2 allowances price that have been formed through the European Trading System (ETS) (Equation (8)).

$$CC_i = E_i \cdot H.R._i \cdot Em.F._j \cdot CP_z \tag{8}$$

where:

CC_i: Purchase cost of CO_2 allowances for the thermal unit i in €

$H.R._i$: Heat rate of the thermal unit i in GJ/MWh

$Em.F._j$: CO_2 emission factor for the fuel j in tn/GJ

CP_z: CO_2 price in €/tn

E_i: Annually produced energy of the thermal unit i in MWh

Finally, the normalized total weighted average variable cost of the interconnected system's thermal units includes the annual maintenance and operation variable costs, as well as the fuel costs of thermal units that operated during the year 2014 and is given by Equation (9).

$$T.W.A.C._{Th.Unit} = \frac{\sum_i (VOMC_i + FC_i)}{\sum E_i} \tag{9}$$

Using Equations (5) to (9), as well as the values of Table A2 (in Appendix), the components of the private cost of the Greek interconnected system's thermal units, and the corresponding total weighted average variable cost were calculated. The calculations have been made for the year 2014. It should be noted that the CO_2 emissions allowances price used in order to calculate the CC_i is equal to 5.94 €/tn (calculated as the average price of CO_2 emission allowances of the year 2014).

In order to calculate the amount of emissions (CO_2, SO_2, NO_x, and $PM_{2.5}$) per thermal unit, so as to arise the weighted average emission factors for the Greek interconnected system, Equation (10) is applied, using the corresponding values of Table A2 (in Appendix).

$$AP_z = Conv.En._i * H.R._i * Em.F._j \tag{10}$$

where:

AP_z: Air pollutant amount i in tn

$Conv.En._i$: Produced energy during year 2014 per thermal unit i in MWh

$H.R._i$: Heat rate of the thermal unit i in GJ/MWh

$Em.F._j$: Air pollutant emission factor per fuel type in tn/GJ

The weighted average emission factor per air pollutant (W.Av.E.F.z) was calculated as the ratio of the total amount of the released emissions to the total energy generated from thermal units. Finally, in order to assess the environmental benefits for renewable technologies (wind, photovoltaics, small hydro) arising from the substitution of the energy produced from conventional fuels, the results of the NEEDS project funded by the European Commission under the 6th Framework Programme have been taken into account. The air pollutants' (NO_x, SO_2 and $PM_{2.5}$) external costs for Greece (prices for 2014) have been calculated according to the methodology developed under ExternE project [42] (Table A3 in Appendix).

As far as the external cost assessment of CO_2 emissions is concerned, it should be mentioned that in 2011 the European Environmental Agency (EEA) adopted a price equal to 33.6 €/tn, based on a methodology developed by the United Kingdom government for assessing carbon cost and its integration into the policy procedure [43]. This price reflects the marginal CO_2 emissions' reduction cost and ranges around the average relevant cost assessed by the Intergovernmental Panel on Climate Change [44], which refers to a range between 3 and 70 €/tn CO_2 (prices for 2014). In order to calculate the marginal environmental benefits arising from the substitution of thermal units with renewable technologies, Equation (11) and the values of Table A3 (in Appendix) and Table A4 (in Appendix) are used.

$$T.Env.Ben._k = \frac{\sum \left(W.Av.E.F._z * Ex.C._z * C.F._k \right)}{C.F._k} \tag{11}$$

where:

$T.Env.Ben._k$: Total environmental benefit of the renewable technology k in €/MWh.

$W.Av.E.F._z$: Weighted average emission factor per air pollutant z in tn/MWh

$C.F._k$: Coefficient factor per renewable technology k in MWh

$Ex.C._k$: External cost per air pollutant in €/tn

3. Results

The application of Equations (5) to (10) lead to **Tables A5(a)-(c)** (in Appendix), where: the amounts of pollutants' emissions, the compounds of private cost, the normalized total weighted average variable cost and the weighted average air pollutants' emission factors of the Greek interconnected system are depicted, for the year 2014.

The normalized total weighted average cost of thermal units equals to 103.5 €/MWh, while the normalized weighted average operation, maintenance and fuel cost equals to 41.2 €/MWh. The weighted average air pollutants emission factors are equal to 1.09 tn/Mwh, 0.0011 tn/MWh, 0.0019 tn/MWh and 0.00006 tn/MWh, respectively for carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxide (NO_x) and particulate matters ($PM_{2.5}$).

The fuel cost of natural gas generation plants appears to be higher than that of lignite units indicating the importance of lignite for the Greek electricity system. Simultaneously, it is obvious that the natural gas units are environmental friendlier than the lignite ones, since their emissions are limited to CO_2 and NO_x, a fact that is related to the unit age and to the fuel type. Finally, the high investment costs of gas generation plants, compared to this of the lignite ones, are mainly attributed to the fact that the prior are newer units, the majority of which were built between year 2010 and 2013 that have not managed to recoup a large percentage of the invested capital.

After calculating the weighted average air pollutants' emission factors of Greek Interconnected System thermal plants (**Tables A5(a)-(c)** in Appendix) and knowing the annual coefficient factor per examined renewable technology (**Table A4** in Appendix), **Table A6** (in Appendix) is composed. In **Table A6** (in Appendix), both the external benefits from non-emitting pollutants—given the substitution of thermal units—and the total external benefit for different values of CO_2, are presented. It should be noted that the total environmental external benefit is the same for all renewable technologies. This is attributed to the fact that the calculations concern only the operating phase of the units, and to the fact that it is considered that the renewable units substitute the same mixture of conventionally produced electricity, regardless of any technological limitations.

According to Equation (3), the guaranteed tariff for each renewable technology should be equal to the sum of the avoided cost of thermal units and the positive and/or negative externalities. For the Greek case—given its specificities (excess of installed capacity, regulated investment cost recovery mechanisms)—it is considered consistent that the avoided cost reflects the total weighted average variable cost of the Greek Interconnected System's thermal units, which is equal to 41.2 € /MWh for the year 2014.

By implementing Equation (4) the new guaranteed tariff, according to the approach of avoided external costs for different values of CO_2 emission cost, arises (**Table 1**). The results shown in **Table 1** are the main finding of the present paper.

Table 1. New and current guaranteed tariffs (€/MWh).

	New FIT (CO_2 6 €/tn)	New FIT (CO_2 11 €/tn)	New FIT (CO_2 34 €/tn)	New FIT (CO_2 70 €/tn)	Current FIT (Law 4254)
Wind (inter/ted)	62	67	92	132	105
Sm. Hydro (<5 MW)	62	67	92	132	105
Sm. Hydro (5 - 15 MW)	62	67	92	132	100
PV (<10 kW)	62	67	92	132	115
PV (<100 kW)	62	67	92	132	69
PV (>100 kW)	62	67	92	132	63.3

As depicted in Table 1, for low and medium CO_2 prices (6, 11 and 34 €/tn) the guaranteed tariffs, after the implementation of avoided cost methodology, are lower than the current ones, since the former were legislated in April 2014.

4. Discussion

In order to boost RES, so as to make them competitive over conventional units, support schemes are being adopted throughout Europe. The most common mechanisms are those wherein the level of RES producer remuneration is administratively determined through a fixed tariff. The majority of the EU States apply cost-based approaches in order to set this tariff level. This means that the key factors for the tariff level are the attractiveness and the financial viability of the investments, rather than the external benefits emanating from the various RES technologies. Nevertheless, according to welfare economics the subsidies offered to RES should reflect their differential external benefit in order not to create competition distortions and at the same time to be socially justified.

As demonstrated by the international literature, there is not a concrete and commonly accepted methodology for assessing the social benefits resulting from the RES penetration in the energy mix, due to the lack of generally accepted externalities valuation methods related to energy security and employment. Typically, this lack is covered by the avoided cost approach wherein the emphasis is given at the calculation of environmental externalities, especially those associated with climate change. These externalities are usually assessed using the results of the European research program ExterneE, as in the case of the Portuguese support mechanism where the external benefit of non-emitting CO_2 is valued and is incorporated in the guaranteed tariff.

In the case of Greece, the low penetration of RES technologies in the domestic energy mix has led, in 2006, to the selection of the financial attractiveness and viability of a renewable unit as criteria for tariff determination, a notion that was maintained and intensified under the Law 3851/2010. Namely, under this Law additional regulatory incentives were offered. For instance, the option for a number of renewable technologies to maintain the guaranteed price "locked" for 18 or 36 months (depending on the unit installed capacity) after signing the power purchase agreement led to over-compensation due to the fact that the guaranteed prices reflected higher manufacturing costs compared to the current ones.

Despite the fact that, since 2006, the economic viability of the RES units has been selected as a criterion for setting the guaranteed tariffs, the compensation mechanism for RES producers adopted in 1999, was maintained. Hence, this raises the paradox of the guaranteed prices to be calculated using financial evaluation methods, while the producers' remuneration to be linked to the SMP, which reflects the avoided marginal cost of thermal units. At the same time, given that RES penetration reduces the SMP, it is concluded that the RES support and compensation mechanism is distorted.

Furthermore, it should be noted that the Greek electricity market, until the end of the year 2013, was fully regulated, providing to all investors (either in the RES sector or the fossil fuel sector) the ability to safely recover their invested capital through mechanisms that are opposed to the basic principles of a liberalized market. By applying the approach of avoided cost in the case of Greece, so as to calculate the guaranteed tariffs of three renewable technologies (wind, solar and small hydro) it was demonstrated that:

- For the year 2014 the total weighted average cost of thermal units is equal to 103.5 € /MWh, while the weighted average variable cost of maintenance, operating and fuel are equal to 41.2 €/MWh.
- The price of carbon dioxide (CO_2) affects catalytically the external benefits per generated RES MWh, compared to the prices of air pollutants such as SO_2, NO_x and PM. Although the computed external environmental benefit is the same for each RES technology, yet the existing guaranteed prices offered to RES producers are varying. For low and medium CO_2 prices (*i.e.* 6, 11 and 34 €/tn) the guaranteed tariffs calculated are lower than the current ones, which were set in April 2014 (**Figure 4**).

By comparing the calculated environmental benefit per RES technology ($T.Env.Ben._k$) (**Table A6** in Appendix) to the difference between the current guaranteed price and the weighted average variable cost of thermal units, which theoretically reflects the social benefits of renewable energy (RES S.B.), it is shown that for CO_2 market prices (*i.e.* 6 €/tn) RES S.B. is three times smaller than $T.Env.Ben._k$. Only for the highest CO_2 prices (higher than 34 €/ton) $T.Env.Ben._k$ is equal or higher compared to RES S.B. (**Figure 5**).

5. Conclusions

As already mentioned, in this article is applied the avoided cost approach in commercially mature renewable technologies (wind, solar, small hydro) with the objective of social justification of RES subsidies in the case of Greece. An important weakness of this approach is that the environmental benefit that arises due to the substitution of thermal plants is the same regardless of the applied renewable technology.

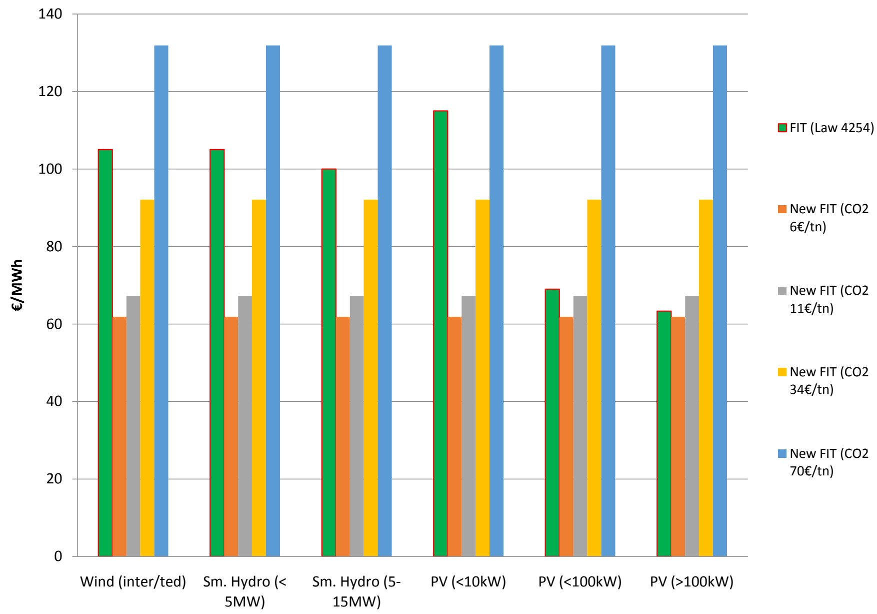


Figure 4. Comparing the current guaranteed tariffs with the tariffs resulting under the approach of avoided cost.

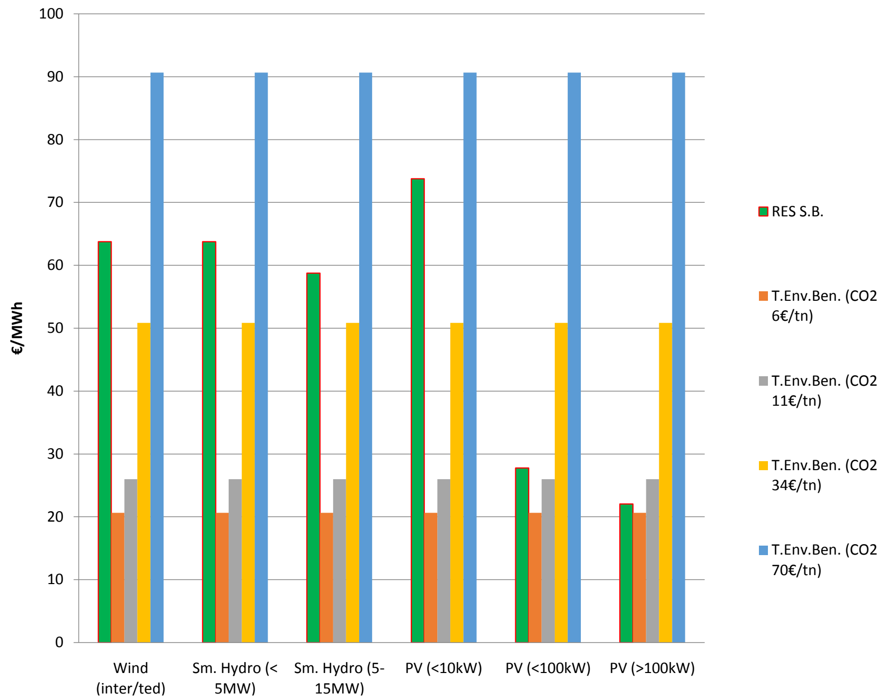


Figure 5. Comparing the calculated environmental benefit with the difference between current tariff and weighted average variable cost.

Regarding the level of the guaranteed price resulting from the implementation of the avoided cost approach it is demonstrated that the current tariffs for wind, small hydro and household photovoltaics (P < 10 kW) are higher by approximately 40% compared to the new ones, which are calculated using the market price of CO_2 (*i.e.* 6 €/ton). Especially for photovoltaics with installed capacity over 10 kW, their current tariffs are almost equal to the calculated new ones, due to the sharp tariff fall. Even in the sensitivity analysis performed for CO_2 prices, it is shown that for low and average CO_2 values (*i.e.* 6, 11 and 34 €/tn), the guaranteed tariffs resulting from the implementation of the avoided cost approach are lower than the current ones for wind, small hydro and household photovoltaics. The current guaranteed prices are justified by the maximum price of 70 €/tn CO_2, which reflects the marginal abatement costs according to the report of the Intergovernmental Panel on Climate Change, indicating an estimated range (in current prices) between 3 - 70 €/tn CO_2.

The abovementioned indicate that, at least in the case of Greece, either the level of the current guaranteed tariffs is not socially justified, or the CO_2 value derived from the European carbon market does not reflect the real social cost. Another point may be that the avoided cost method, alone, is not adequate to explain the level of subsidies. Finally, in light of the foregoing, the need for the development of a concrete and integrated methodology for calculating all RES externalities emerges.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. Renewable Energy Sources guaranteed tariffs according to Law 4254/2014.

	RES Technology	Guaranteed Tariff (€/MWh) with grants	Guaranteed Tariff (€/MWh) without grants
1	On shore wind ≤ 5 MW (interconnected)	105	85
2	On shore wind > 5 MW (interconnected)	105	82
3	On shore wind (non-interconnected)	110	90
4	Small Hydro ≤ 1 MWe	105	85
5	Small Hydro (1 MWe to 5 MWe)	105	83
6	Small Hydro (5 MWe to 15 MWe)	100	80
7	Concentrated Solar Plants without storage	260	200
8	Concentrated Solar Plants with storage	280	220
9	Low enthalpy geothermal	143	130
10	High enthalpy geothermal	110	100
11	Biomass incineration ≤ 1 MW	198	180
12	Biomass incineration (1 MW to 5 MW)	170	155
13	Biomass incineration > 5 MW	148	135
14	Landfill Biogas ≤ 2 MW	131	114
15	Landfill Biogas > 2 MW	108	94
16	Anaerobic digestion biogas ≤ 3 MW	230	209
17	Anaerobic digestion biogas > 3 MW	209	190
18	Photovoltaics < 100 kW (interconnected)	$1.2*\mu SMP_{\nu-1}*$	
19	Photovoltaics > 100 kW (interconnected)	$1.1*\mu SMP_{\nu-1}$	
20	Photovoltaics (non interconnected)	$1.1*\mu SMP_{\nu-1}$	
21	Household photovoltaics < 10 kW	115	

*Where $\mu SMP_{\nu-1}$ equals to the average SMP during the previous year ($\nu-1$).

Table A2. Emission factors, unit investment cost, Heat Rate, LHV and Fuel cost for the thermal plants of the Greek interconnected system.

PPC Lignite Units	TC (€/MW)	Heat Rate (GJ/MWh)	Fuel Cost (€/tn)	LHV (kcal/kg)	Emission factors (tn/GJ)			
					CO_2	SO_2	NO_x	$PM_{2.5}$
AG_DIM1	1,700,000	10.6	11.89	1260	1.27E−01	1.45E−04	2.17E−04	7.90E−06
AG_DIM2	1,700,000	10.6	11.89	1260	1.27E−01	1.45E−04	2.17E−04	7.90E−06
AG_DIM3	1,700,000	10.4	11.89	1260	1.27E−01	1.45E−04	2.17E−04	7.90E−06
AG_DIM4	1,700,000	10.4	11.89	1260	1.27E−01	1.45E−04	2.17E−04	7.90E−06
AG_DIM5	1,700,000	9.6	11.89	1260	1.27E−01	1.45E−04	2.17E−04	7.90E−06
KARDIA1	1,700,000	11.4	13.69	1196	1.27E−01	1.45E−04	2.17E−04	7.90E−06

Continued

KARDIA2	1,700,000	11.4	13.69	1196	1.27E−01	1.45E−04	2.17E−04	7.90E−06
KARDIA3	1,700,000	10.6	13.69	1196	1.27E−01	1.45E−04	2.17E−04	7.90E−06
KARDIA4	1,700,000	10.6	13.69	1196	1.27E−01	1.45E−04	2.17E−04	7.90E−06
PTOLEM/DA3	1,700,000	10.2	12.05	1345	1.27E−01	1.45E−04	2.17E−04	7.90E−06
PTOLEM/DA4	1,700,000	9.8	12.05	1345	1.27E−01	1.45E−04	2.17E−04	7.90E−06
MEGAL/LI3	1,700,000	10.8	9.56	1113	1.27E−01	1.45E−04	2.17E−04	7.90E−06
MEGAL/LI4	1,700,000	10.9	9.56	1113	1.27E−01	1.45E−04	2.17E−04	7.90E−06
AMYNDEO1	1,700,000	10.7	19	1440	1.27E−01	1.45E−04	2.17E−04	7.90E−06
AMYNDEO2	1,700,000	10.7	19	1440	1.27E−01	1.45E−04	2.17E−04	7.90E−06
MELITI	1,700,000	8.9	19	1440	1.27E−01	1.45E−04	2.17E−04	7.90E−06
PPC N. Gas Units	**TC (€/MW)**	**GJ/MWh**	**€/Nm^3**	**kcal/Nm^3**	**CO_2**	**SO_2**	**NO_x**	**$PM_{2.5}$**
LAVRIO_CC_4	700,000	7.81	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
LAVRIO_CC_5	700,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
KOMOTINI	700,000	7.535	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
ALIVERI5	700,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
IPPS N.Gas Units	**TC (€/MW)**	**GJ/MWh**	**€/Nm^3**	**kcal/Nm^3**	**CO_2**	**SO_2**	**NO_x**	**$PM_{2.5}$**
ENTHES	625,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
ELPEDISON	655,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
HERON_Viotia	690,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
PROTERGIA	787,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
KOR.POWER	704,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08
ALOUMINION	689,000	6.831	0.46	9500	5.67E−02	1.69E−07	8.90E−05	5.00E−08

Table A3. External cost of emissions (€/tn).

Emissions	External Cost (€/tn)
SO_2	6.596
$PM_{2.5}$	9.885
NO_x	3.221
CO_2	11

Table A4. Average coefficient factors per RES technology.

	Wind		Small Hydro		Photovoltaics		
	Interconnected system	Non Interconnected system	Up to 5 MW	5 - 15 MW	≤10 kW	≤100 kW	>100 kW
Coefficient factor (annual hours/MW)	2146	2628	3066	3373	1314	1445	1445

Table A5. (a) Emissions and costs of the Greek interconnected system's lignite based thermal plants (year 2014); (b) Emissions and costs of the Greek interconnected system's natural gas based thermal plants (year 2014); (c) Total Emissions and total normalized costs of the Greek interconnected system's thermal plants (year 2014).

(a)

YEAR 2014	Emissions (tn/y)				Fixed Costs (€/MWh)		Variable Costs (€/MWh)			
PPC Lignite Units	CO_2	SO_2	NO_x	$PM_{2.5}$	Investment cost	O&M cost	O&M cost	Fuel Cost	CO_2 purchase cost	Total cost
AG_DIM1	1,814,717	2071	3099	113	19.3	8.1	1.2	23.9	8.1	60.6
AG_DIM2	1,824,319	2082	3115	113	19.6	8.1	1.2	23.9	8.1	60.9
AG_DIM3	1,976,221	2255	3374	123	18.4	7.6	1.2	23.5	7.9	58.5
AG_DIM4	1,891,936	2159	3231	118	19.6	7.9	1.2	23.5	7.9	60.1
AG_DIM5	2,854,705	3257	4875	177	20.7	5.8	1.2	21.7	7.3	56.7
KARDIA1	1,890,953	2158	3229	118	17.1	8.4	1.2	31.2	8.7	66.6
KARDIA2	1,324,963	1512	2262	82	24.4	12.0	1.2	31.2	8.7	77.6
KARDIA3	2,007,906	2291	3429	125	16.8	7.5	1.2	29.0	8.1	62.6
KARDIA4	2,280,744	2602	3894	142	14.8	6.6	1.2	29.0	8.1	59.7
PTOLEMAIDA3	556,745	635	951	35	19.2	10.8	1.2	21.8	7.8	60.9
PTOLEMAIDA4	1,433,162	1635	2447	89	18.9	9.5	1.2	21.0	7.5	58.1
MEGALOPOLI3	2,104,881	2402	3594	131	14.8	6.7	1.2	22.2	8.2	53.0
MEGALOPOLI4	2,105,598	2402	3595	131	21.1	6.7	1.2	22.4	8.3	59.7
AMYNDEO1	1,773,087	2023	3028	110	21.3	8.4	1.2	33.7	8.2	72.8
AMYNDEO2	2,060,543	2351	3518	128	18.4	7.2	1.2	33.7	8.2	68.7
MELITI	1,946,490	2221	3324	121	35.2	6.7	1.2	28.1	6.8	78.0

(b)

YEAR 2014	Emissions (tn/y)				Fixed Costs (€/MWh)		Variable Costs (€/MWh)			
PPC N. Gas Units	CO_2	SO_2	NO_x	$PM_{2.5}$	Investment cost	O&M cost	O&M cost	Fuel Cost	CO_2 purchase cost	Total cost
LAVRIO_CC_4	566,256	2	888	0	24.4	11.1	2.5	89.6	6.0	133.6
LAVRIO_CC_5	303,436	1	476	0	44.2	12.4	2.5	78.4	5.2	142.7
KOMOTINI_CC	153,578	0	241	0	88.9	34.2	2.5	86.4	5.7	217.7
ALIVERI5	588,717	2	924	1	199.3	7.1	2.5	78.4	5.2	292.5
IPPS N.Gas Units										
ENTHES	161,849	0	254	0	76.9	24.1	2.5	78.4	5.2	187.0
ELPEDISON	212,067	1	333	0	135.2	19.3	2.5	78.4	5.2	240.6
HERON_Viotias	233,682	1	367	0	133.9	16.1	2.5	78.4	5.2	236.1
PROTERGIA	176,002	1	276	0	272.3	24.6	2.5	78.4	5.2	383.0
KORINTHOS POWER	125,627	0	197	0	495.5	34.5	2.5	78.4	5.2	616.1
ALOUMINION	451,960	1	709	0	36.4	8.4	2.5	78.4	5.2	130.9

(c)

YEAR 2014	Emissions (tn/y)				Fixed Costs (€/MWh)		Variable Costs (€/MWh)			
	CO_2	SO_2	NO_x	$PM_{2.5}$	Investment cost	O&M cost	O&M cost	Fuel Cost	CO_2 purchase cost	Total cost
TOTAL	32,820,141	34,064	55,629	1858						
Normalized figures per MWh	1.09E+00	1.14E−03	1.85E−03	6.19E−05	45.6	9.4	1.5	39.7	7.3	103.5

Table A6. External benefit per renewable MWh.

	External benefit (€) per emission during unit operation							Total external benefit (€/MWh) for different CO_2 prices			
	SO_2	$PM_{2.5}$	NO_x	CO_2 6 €/tn	CO_2 11 €/tn	CO_2 34 €/tn	CO_2 70 €/tn	CO_2 6 €/tn	CO_2 11 €/tn	CO_2 34 €/tn	CO_2 70 €/tn
Wind (inter/ted)	16.07	1.31	12.82	14.09	25.55	78.89	164.35	21	26	51	91
Small Hydro (<5 MW)	22.97	1.88	18.31	20.13	36.50	112.71	234.81	21	26	51	91
Small Hydro (5 - 15 MW)	25.27	2.07	20.14	22.14	40.15	123.99	258.32	21	26	51	91
PV (<10 kW)	9.84	804	7.85	8.63	15.64	48.30	100.63	21	26	51	91
PV (<100 kW)	10.82	885	8.63	9.49	17.20	53.12	110.67	21	26	51	91
PV (>100 kW)	10.82	885	8.63	9.49	17.20	53.12	110.67	21	26	51	91

Nomenclature

CASES—Cost Assessment for Sustainable Energy Systems	Research Project funded by the European Commission under the Sixth Framework Programme (FP6)n
CBP	Competitive Bidding Processes
CO_2	Carbon Dioxide
CRM	Capacity Remuneration Mechanism
DAS	Day-ahead Scheduling
DIM	Daily Imbalances Market
EC	European Commission
EEA	European Environmental Agency
ETS	European Trading System
ETMEAR	Special Fee for the Reduction of Greenhouse Gases Emissions
ExternE—External Costs of Energy	A series of research projects starting from early 90s till 2005 funded by the European Commission
EU	European Union
FIT	Feed in Tariff
FIP	Feed in Premium
IPTO	Independent Power Transmission Operator
IRR	Internal Rate of Return

Continued

LAGIE	Electricity Market Operator
LCOE	Levelized Cost of Energy
LHV	Lower Heating Value
NEEDS—New Energy Externalities Development for Sustainability	Research Project funded by the European Commission under the Sixth Framework Programme (FP6)n
NO_x	Nitrogen Oxide
NPV	Net Present Value
$PM_{2.5}$	Particulate Matter that has a diameter of less than 2.5 micrometers
PPA	Power Purchase Agreement
PV	Photovoltaic
PURPA	Public Utility Regulatory Policies Act
REN21	Renewable Energy Policy Network for the 21st Century
RES	Renewable Energy Sources
RES S.B.	Social Benefits of Renewable Energy
SIMP	System Imbalance Marginal Price
SMP	System Marginal Price
SO_2	Sulfur Dioxide
T.Env.Ben.	Total Environmental Benefit per RES technology
TGC	Tradable Green Certificates
TS	Tender Schemes
WAVCTU	Weighted Average Variable Cost of Thermal Units