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Analysing the effect of the sliding feed-in premium scheme to the revenues of a wind farm with the use of mesoscale data - case study of Greece

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Abstract. One of the main challenges of the wind industry is the accurate prediction of the revenues that a developing project is expected to produce during its operation lifetime. The European Commission's Guidelines on State Aid for Environment Protection and Energy 2014-2020 (2014/C 200/01) (European Commission, 2014), enforced the transition from the Feed-in Tarif (FiT) scheme to a market-oriented Feed-in Premium remuneration mechanism. This evolution creates additional uncertainty when evaluating the revenues of a wind energy project, since the remuneration of the produced energy is now market depended instead of stable, as it was under the FiT scheme. The present study attempts to estimate the level of uncertainty that the change of support scheme creates. The expected revenues under both schemes are calculated for three (3) continuous years in the Greek market with the assumption that the strike price of the new FiP scheme coincides with the fixed tariff of the FiT scheme and the results are compared in an annual and total period. The study takes into account the revenues from the day-ahead market (i.e. the only wholesale market currently exists in Greece) and from the support mechanism. The results of the comparison reveal small fluctuation in the annual revenues of the wind stations examined between the two schemes, which does not seem to increase when examining the total 3-year period

1. Introduction

Greek wind energy market was operating under a feed-in tariff scheme (hereinafter "FiT") up to the end of 2015. The FiT scheme formulated a protected environment for investors, since wind energy plants were compensated according to a constant, pre-defined tariff for the 20-year validity period of the Power Purchase Agreement (PPA) of each project.

The European Commission's Guidelines on State Aid for Environment Protection and Energy 2014-2020 (2014/C 200/01) (European Comission, 2014), hereinafter "EEAG 2014-2020", enforced the transition from the FiT scheme to a market-oriented feed-in premium mechanism (hereinafter "FiP"). Law 4414/2016 (OG 149A, 9.8.2016) - which enforced the new supporting scheme in Greece - determined that new wind projects will receive a premium on top of their income from the market, in the form of a variable (sliding) premium. In practice the sliding premium is calculated, on a monthly basis, as the difference between a Reference Value ("RV") and the hourly market price (the System Marginal Price or "SMP"). Moreover, from 1.1.2017 onwards, the RV is determined through auctions announced and executed by Regulatory Authority for Energy (RAE).

The present study investigates the abovementioned schemes for the case of the Greek wind energy market, with respects to estimating wind farm revenues under both schemes.

The scope of the present study is to evaluate and quantify the effect that the change of the supporting scheme will have on the revenues of wind projects in various locations in Greece.

2. Basic principles of the two remuneration schemes

The following paragraphs briefly describe the remuneration schemes, previous and existing, that have been applied in the Greek wind energy market.

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2.1. The previous remuneration scheme: Feed-in tariff (FiT)
Until 2015 the development of wind energy in Greece was governed by a feed-in tariff (FiT) scheme, according to which the investors were compensated a by-law pre-defined tariff for a 20-year period, according to a Power Purchase Agreement (PPA) between project company and the market operator.

The FiT had a value of 73 €/MWh on 2006, where at the end of 2015 was 105 €/MWh. Both values refer to projects located in the interconnected system. Further, the value of 2015 refer to projects that don't receive state subsidy for their construction.

2.2. The new remuneration scheme: Feed-in premium (FiP)
In compliance with the European Commission's Guidelines on State Aid for Environment Protection and Energy 2014-2020 (Official Journal of EU, 2014/C 200/01, par. 124-131), wind projects in Greece which had not signed a Power Purchase Agreement (PPA) until the end of 2015, will be remunerated through a Feed-in premium (FiP) mechanism. The basic provisions for the operation of the FiP scheme in Greece, have as follows:

i) The wind projects receive a premium in the form of a variable (sliding) premium, on top of their income from the market. The premium is calculated on a monthly basis and its sum with the hourly market price, practically targets a strike price, the so-called Reference Value (RV). For year 2016, the RV for wind projects was defined by law at 98€/MWh. From 1.1.2017 onwards the RV is defined per project through auctions organized by the Regulatory Authority of Energy (RAE). The first auction, held on 2.7.2018, determined RVs between 68,18 €/MWh and 71,93 €/MWh. As long as the RV is being defined for a project, it remains valid for 20 years (contract with the Electricity Market Operator).

ii) The wind projects will sell their electricity directly to the market, while they will be subject to balancing responsibilities, unless no liquid intra-day market exists. In order to meet these market obligations, the wind projects receive, on top of their remuneration, a management fee equal to 2€/MWh. Finally, the wind projects have the option to outsource their market obligations to other entities, the Aggregators, while the Electricity Market Operator has been defined as a Last-resort Aggregator.

3. Methodology applied
In order to calculate the revenue of a wind farm under the FiP regime, energy production information for each and all of the wind projects of the country would be needed. Since production data from the existing wind farms are not available to the public, the approach was to investigate whether the use of mesoscale wind data in representative locations (where wind farms are located) would provide accurate enough results so that a comparison between the two schemes could be made.

Given that the main purpose of the study is the comparative assessment of the two different remuneration schemes, the absolute energy production values are not indispensable, as long as the wind resource assessment provides valid and consistent results in both cases to be compared. Moreover, in the case of the FiP calculation, it is essential to know the variation of the energy production in an hourly basis, since this is needed to be combined with the hourly System Marginal Price (SMP) (Hellenic Transmissions System Operator, n.d.) values in order to estimate the premium for every station. Hence, it was decided to use mesoscale wind data (EMD International A/S;, n.d.) because of the high correlation factors they have shown in the past, when compared with actual wind measurements (Foussekis & Gkarakis, 2014).

The regions of the country where wind farms are located have been identified from the official data from the Greek Regulatory Authority for Energy. A total of 45 representative locations were eventually selected for which the mesoscale data sets were acquired. In each of these locations a representative nominal capacity was assigned, derived from the annual wind statistics report of the Hellenic Wind Energy Association (HWEA) (Hellenic Wind Energy Association, n.d.), so that eventually each of these locations represent a virtual wind station (see Appendix 1) which is representative of the actual spatial distribution of the total operating wind capacity in Greece.

A calculation model was created, in order to match, for each wind station, the hourly wind data with the power curve of a typical 3 MW wind turbine. The calculated total energy production was then compared to the official data from the Hellenic Electricity Market Operator (Hellenic Electricity Market Operator, n.d.) on a monthly and yearly basis, in order to verify the accuracy of the results. Based on that comparison, a correction factor was applied to the calculations, so that the calculated production was adjusted to match the official total wind energy production on an annual basis.

The results of the energy calculations confirm the initial assumptions, since the monthly calculated results present indeed high correlation with the actual production figures on an hourly basis (R^2~ 0,9, see following graphs).

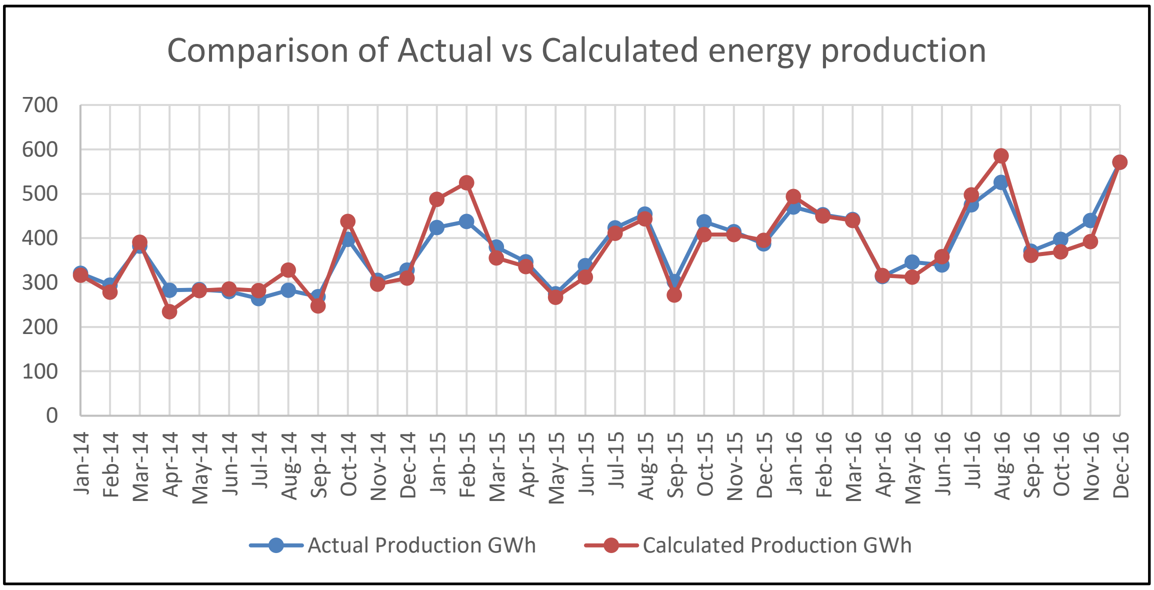

Figure 1. Comparison of Actual vs Calculated energy production.

Finally, the calculated energy production values were used to estimate the revenue of each wind station for both FiT and FiP schemes, with the fair assumption that the tariff of the FiT coincides with the strike price of the FiP scheme.

3.1. Selection of representative locations for wind stations

The first step was to determine representative wind stations for which to estimate the revenues under both FiT and FiP schemes. Due to the lack of analytical public data for the energy production of the operating wind farms in Greece, it was inevitable to define virtual wind stations, hereinafter the "wind stations", for each one of them the remuneration was then calculated for the above-mentioned schemes.

In order to obtain accurate results, a large number of candidate locations were selected, spread in all over the country in representative location according to where the operating wind farms are located. Particularly, 51 locations were initially selected for the virtual wind stations.

For each one of the locations, hourly mesoscale wind speed data at 100 m a.g.l. from EMD & ConWx were used, covering the period 01.01.2014-31.12.2016. Due to the fact that 6 locations presented extremely low wind potential (<4m/s @ 100 m a.g.l.), they were finally rejected and no further analysis was conducted from them. Thus, 45 locations constitute the final list of wind stations' locations used for the present study. The basic information (coordinates, wind speed and map) for the abovementioned locations are presented in Appendix 1.

3.2. Power capacity allocation to wind stations

The next step was to allocate the power capacity for each one of the 45 selected wind stations at the locations of Table 1. In order to match a representative capacity for each wind station with regards to the actual distribution of the total installed wind capacity in Greece, the following methodology was performed (it is noted that the methodology described represents year 2014, while similar methodology was used for the years 2015 and 2016 accordingly).

The first step was to calculate the annual average wind capacity for all the country.

In order to estimate an annual average wind capacity in Greece, the monthly reports of EMO (LAGIE) for the RES Special Account were used. The following Table illustrates the total installed wind capacity in Greece (interconnected system & non-interconnected islands) at the end of each month of the year 2014. The corresponding data for whole examined period are presented in Appendix 2.

Table 1. Total installed wind capacity in Greece for 2014.
Source: EMO's report for RES Special Account for January 2015.

Jan-14	1827
Feb-14	1847
Mar-14	1847
Apr-14	1847
May-14	1847
Jun-14	1884
Jul-14	1902
Aug-14	1902
Sep-14	1902
Oct-14	1910
Nov-14	1933
Dec-14	1978
Annual Average	**1885,50**

The second step was to allocate the wind capacity to each wind station accordingly.

In order to allocate the aforementioned average capacity to the wind stations, the annual "wind statistics report" of Hellenic Wind Energy Association (HWEA) for the period 2014-2016, were used. Due to the fact that HWEA reports present the installed capacity per administrative region, as an intermediate step, the annual average capacity of step 1 was primarily allocated per region. The actual capacity per region derives from the data of HWEA report for 2014 (see Table 2).

Subsequently, the values of actual capacity per region were normalized according to the mean annual capacity of 1885,50 MW calculated. Hence, new normalized values for wind capacity per region were calculated for year 2014. Finally, it was assumed that the normalized wind capacity of each region is equally distributed to the virtual wind stations selected in that region. Table 2 consolidates the aforementioned calculations.

Table 2. Estimation of the wind capacity for each wind station

Region	Actual capacity at the end of the year	Normalised capacity [MW]	Number of wind stations	Capacity of each wind station of Region [MW]
Attica	83,32	79,35	3	26,45
North Aegean	36,04	34,32	3	11,44
Western Macedonia	52,9	50,38	3	16,79
Western Greece	130,35	124,14	5	24,83
Ionion Islands	83,7	79,71	2	39,86
Central Macedonia	41	39,05	2	19,52
Crete	193,4	184,19	7	26,31

South Aegean	88,81	84,58	3	28,19
Peloponnese	367,95	350,42	6	58,40
Central Greece	602,8	574,08	6	95,68
Thessalia	17	16,19	2	8,10
East. Macedonia & Thrace	282,55	269,09	3	89,70
Total	**1979,82**	**1885,50**	**45**	

The complete HWEA reports and relevant calculations for the capacity of each wind station for the whole period (2014-2016) are presented in Appendix 3.

3.3. Estimation of wind energy production

The energy production for each virtual wind station was calculated on hourly basis for the period 01.01.2014-31.12.2016. For this purpose, the following data were used:

i) hourly mesoscale wind speed data for each wind station at 100 m a.g.l covering the period 2014-2016
ii) the power curve of a 3 MW wind turbine of a dominant manufacturer in the Greek wind industry
iii) the capacity in MW for each wind station derived from the previous paragraph for each year of the examined period

Particularly, the hourly wind speed values were matched to the power curve of the selected WTG type and the value derived was then adjusted according to the capacity assigned for each wind station in order to calculate the hourly energy production for each one of the 45 wind stations.

The total wind energy production for 2014 for the amount of the wind stations was estimated at **4.254 GWh**. This number is quite close to the value of **3.689 GWh** (13,28% deviation) which was the actual wind energy production of that year, considering that mesoscale data were used instead of actual wind measurements and without taking into consideration availability and grid losses.

In order to adjust the calculated wind energy production (4.254 GWh) to the actual annual energy production (3.689 GWh), a correction factor of 86,72% was applied resulting in the **normalized** annual energy production for each wind station. Finally, the cumulative energy production per region was calculated, which is presented in the following table.

Table 3. Estimated annual energy production per Region for 2014

Region	Normalised capacity [MW]	Estimated annual energy production [MW]	Normalized annual energy production [MW]
Attica	79,35	204,11	177,00
North Aegean	34,32	97,56	84,60
Western Macedonia	50,38	52,41	45,45
Western Greece	124,14	181,07	157,02
Ionion Islands	79,71	132,84	115,20
Central Macedonia	39,05	42,07	36,48
Crete	184,19	554,03	480,44
South Aegean	84,58	256,75	222,65
Peloponnese	350,42	584,38	506,76
Central Greece	574,08	1393,37	1208,28
Thessalia	16,19	30,77	26,68
East. Macedonia & Thrace	269,09	724,73	628,46

Total	**1885,50**	**4.254,09**	**3689,00**

3.4. Calculation of remuneration under both schemes

3.4.1. Remuneration under the FiT scheme. In order to estimate the compensation of each wind station for the scenario of a FiT scheme, it was assumed a stable tariff of 98 €/MWh which is actually the **Reference Value (RV)** that Law 4414/2016 (OG 149A) introduced for wind projects installed either in interconnected system or non-interconnected islands. It is mentioned that according to the Ministry of Energy, the Reference Value determined for each RES technology is actually reflecting the Levelized Cost of Energy (LCOE) of the corresponding technology. Subsequently, the compensation of each wind station under a FiT scheme was estimated on an hourly basis, by multiplying the assumed Feed-in Tariff, i.e. the Reference Value with the hourly energy production **(Q_h),** as follows:

$$\boldsymbol{Total\ Income_{FiT,h} = RV * \sum_{h=1}^{n} Q_h} \qquad (1)$$

3.4.2. The concept of the FiP Scheme. According to the new RES/CHP support scheme, effective from 01.01.2016, the Total Income of the amount of the operating stations of a given RES technology is calculated on a monthly basis (calculation period). Most of the aforementioned Total Income is secured from the energy market, in the form of a Market Income. In addition to the Market Income, a new type of operating aid has been introduced for the electricity generation from RES in the form of a **sliding premium (sFiP)**. The total monthly premium for all the stations of a given RES technology is estimated as follows:

$$\boldsymbol{Total\ Premium_{m,RES\ tech.} = Total\ Income_{m,RES\ tech.} - Market\ Income_{m,RES\ tech.}} \quad (2)$$

The Total Income and the Market Income are calculated with the following equations, subject to the assumption that all power plants enjoy the same Reference Value (RV):

$$\boldsymbol{Total\ Income_{m,RES\ tech.} = RV * \sum_{ws=1}^{k} \sum_{h=1}^{n} Q_{ws,h}} \quad (3)$$

$$\boldsymbol{Market\ Income_{m,RES\ tech.} = \sum_{ws=1}^{k} \sum_{h=1}^{n} AVE_h * Q_{ws,h}} \quad (4)$$

where:
m: *month (calculation period)*
k: *the total number of operating stations of a given RES technology*
n*: the total hours of the month in which there was participation of a RES technology in the* ***Day-Ahead Scheduling (DAS)***
h*: the hour that a RES technology participated in the DAS*
$Q_{ws,h}$*: the produced energy of a given wind station (ws) injected in the electrical grid at hour h*
AVE_h*: The Average Value of Energy at hour h*

It is obvious from the above equations that the total monthly income for all stations of a given RES technology with the FiP scheme coincides with the expected total monthly income of those stations with the FiT scheme, as long as it is actually the product of the Reference Value with the total energy produced in the examined period (month).

However, it is underlined that while the FiP scheme distributes the same total amount, to the total RES producers, as if they were operating under a FiT scheme, the income of each one RES producer is differentiated in the FiP scheme, as analyzed in the following paragraph.

3.4.3. Calculating the remuneration under the FiP Scheme. The Total Income of a wind station (ws) is calculated on a monthly basis (calculation period) and consists of two separate amounts: The Market Income and a state aid (premium) granted on top of the Market Income.

$$\boldsymbol{Total\ Income_{m,ws} = Market\ Income_{m,ws} + premium_{m,ws}} \qquad (5)$$

all amounts in Euros (€), m: month, ws: wind station
The Market Income of each wind station is estimated as follows:

$$\boldsymbol{Market\ Income_{m,ws} = \sum_{h=1}^{n} AVE_h * Q_{ws,h}} \ (6)$$

where:
AVE_h: the Average Value of Energy at hour h
h: the hour that a RES technology participated in the DAS
The calculation of the hourly Average Value of Energy (AVEh) is based on the hourly System Marginal Price (SMP_h) and the hourly value of the Wholesale Energy Market mechanisms (WEM_h):

$$\boldsymbol{AVE_h = SMP_h + WEM_h} \ (7)$$

all values in €/MWh

Given that:

i) The AVE_h is basically determined by the **SMP_h**

ii) the exact methodology for the calculation of the **WEM_h** is still pending

it is assumed in the present study that the AVE_h coincides with the **SMP_h,** i.e.:

$$\boldsymbol{AVE_h \cong SMP_h} \ (8)$$

Thus, for the present study the Market Income is actually calculated with the following equation:

$$\boldsymbol{Market\ Income_{m,ws} = \sum_{h=1}^{n} SMP_h * Q_{ws,h}} \ (9)$$

On top of the Market Income, each wind station also collects a premium from the Special RES account. The amount of the premium (in €) is based on the calculation of a sliding feed-in premium in €/MWh (sFiP), which is calculated on a monthly basis. For this reason, a new variable is introduced, the **MArket Special Price** ("MASP"), which is calculated by EMO (LAGIE) for each RES technology on a monthly basis (in €/MWh). The calculation of the monthly sFiP has as follows:

$$\boldsymbol{sFiP_m = RV_{ws} - MASP_{wind-energy,m}} \ (10)$$

where:
RVws: *Reference Value of each wind station (defined by auctions from 01.01.2017 onwards)*
MASP: *Market Special Price calculated per month for each RES technology (common for all wind stations)*

The MASP actually reflects the weighted Average Value of Energy (AVE). According to the provisions of article 3 of Ministerial Decision RF187480/7.12.2016 (OG 3955 B), the MASP for non-controllable RES, like wind energy, is calculated as follows:

$$\boldsymbol{MASP_{RES\ tech,m} = \frac{\sum_{h=1}^{n} AVE_h * Q_{RES\ tech,h}}{\sum_{h=1}^{n} Q_{RES\ tec,h}} \approx \frac{\sum_{h=1}^{n} SMP_h * Q_{RES\ tech,h}}{\sum_{h=1}^{n} Q_{RES\ tec,h}}} \ (11)$$

where:
n: *the total hours of the month in which there was participation of a RES technology in the DAS*
h: *the hour that a RES technology participated in the DAS*
$Q_{RES\ tech,h}$: *the total produced energy for a given RES technology injected in the electrical grid at hour h*
AVE_h*: the Average Value of Energy at hour h*
SMP_h: *the System Marginal Price at hour h*
*Note: the **AVE_h** was assumed to be equal with the **SMP_h,** for the reasons mentioned before.*

It is stressed that for the calculation of the total injected energy of a given RES technology per hour ($Q_{RES\ tech,h}$), the amount of the power plants of that RES technology are taken into account, regardless their supporting scheme (FiT or FiP).

The above equation for the calculation of the MASP illustrates the necessity for market responsiveness for the wind stations participating in a FiP scheme. Particularly, the wind stations should maximize their energy production during the periods of high value of energy price, i.e. they should have a positive correlation with the SMP.

With respects to the input data for the above equation, it is mentioned that the hourly SMP values (SMP_h) for the examined period were taken by the relevant reports of Hellenic Transmission System Operator (HTSO, "ADMIE" in Greek), while the hourly produced energy for the case of wind energy ($Q_{wind\text{-}energy,h}$) has already been estimated according to the methodology presented.

Taking the estimated values of the MASP, the monthly values of the sFiP are calculated with the use of equation 10. The following Table presents the estimated values of the Market Special Price and $sFiP_m$ for each month of the year, for the case of wind energy and for the year 2014.

Table 4. Estimated Market Special Price (MASP) for wind energy according to the input data (production of wind stations, SMP_h) for year 2014.

Month	$MASP_m$ [€/MWh]	$sFiP_m$ [€/MWh]	SMP_m [€/MWh]
Jan	65,15	32,85	64,63
Feb	65,03	32,97	66,64
Mar	46,99	51,01	47,61
Apr	49,25	48,75	51,29
May	44,56	53,44	45,97
Jun	48,67	49,33	49,50
Jul	76,79	21,21	70,03
Aug	56,73	41,27	57,80
Sep	52,07	45,93	55,98
Oct	52,00	46,00	53,41
Nov	59,40	38,60	62,06
Dec	62,70	35,30	65,15
Average	**56,61**	**41,39**	**57,51**

[a] The monthly SMP is also presented for comparison reasons

From the above analysis derives that the Market Special Price (€/MWh) is not actually a price that each RES producer is compensated. It is a price introduced with the sole purpose to estimate the monthly value of the $sFiP_m$ (also in €/MWh).

It is mentioned that in the case of the present study, where all wind stations are assumed to have the same Reference Value of 98 €/MWh, the value of $sFiP_m$ for each month is common for all wind stations.

Finally, the premium (in €) each wind station receives is determined according to the provisions of Law 4416/2016 and MD 187480/7.12.2016 (OG3955B). Particularly, the premium, which depends on the produced energy of each wind station over the calculation period (month), is calculated with the following equation:

$$\boldsymbol{premium = \left(RV_{ws} - MASP_{wind-energy,m}\right) X \left(Q_{ws,m} - Q_{ws,m,SMP=0|t>2h}\right)} \quad \textbf{(12)}$$

where:
RV_{ws}: *the RV that a wind station has secured*
$MASP_{wind\text{-}energy,m}$: *the MASP value for month m for wind projects*
$Q_{ws,m}$: *the total produced energy of a wind station for month m*
$Q_{ws,m}$, $SMP=0|t>2h$: *the energy produced by the wind station over the month m, where the SMP=0 for over 2 hours (cf. Law 4416/2016, article 5, par.10 & MD 187480/7.12.2016, article 5, par.3)*

The monthly income under a FiP scheme was calculated per wind station, as well as per region for the examined period (2014-2016). The results are presented in Appendix 6. As expected, the total monthly income for all wind stations is the same for FiT and FiP schemes (see last column of Tables in Appendices 4 and 6).

4. Results from the comparison

The results of the comparison reveal small fluctuation in the annual revenues of each wind station between the two schemes, which does not seem to increase when examining the total 3-year period (analytical results per station per year are presented in Appendix 7)

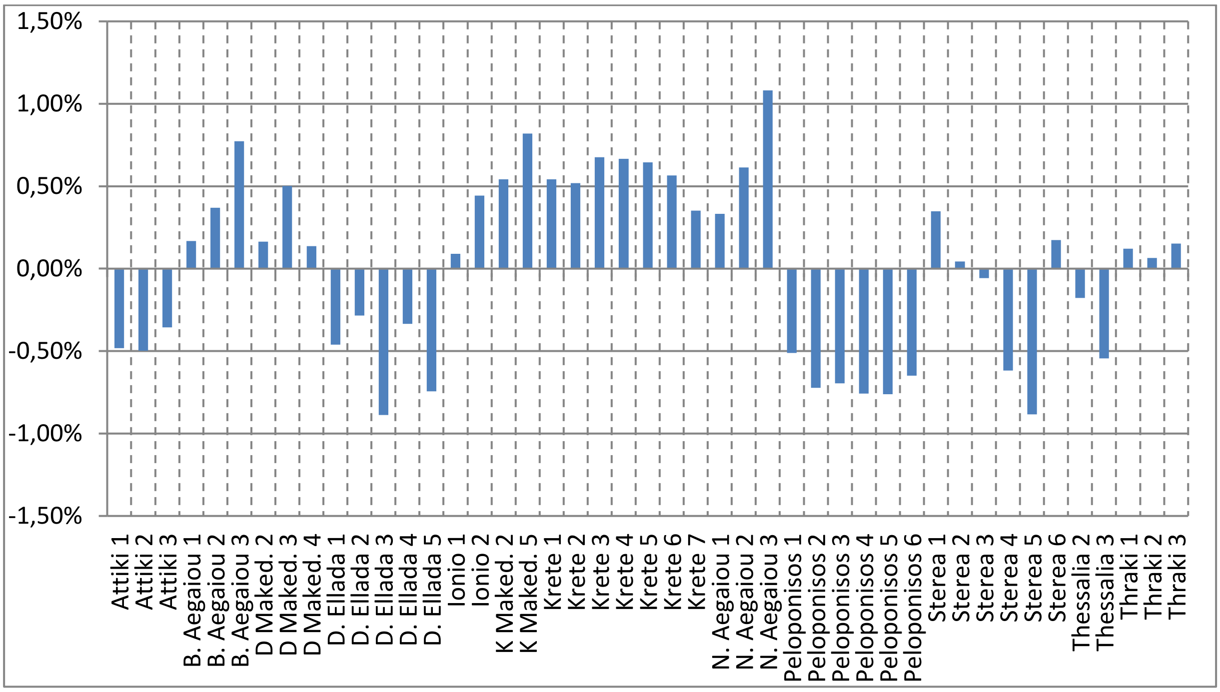

Figure 2. Comparison of revenues under FiT & FiP schemes for the period 2014-2016 for 45 representative locations of wind farms in Greece

5. Conclusions

Combining hourly mesoscale wind data for selected locations (representative to the actual installed capacity in Greece) with hourly SMP data can provide accurate results regarding the energy production and hence the total revenues of wind stations for the case of Greece, as these are derived by the day-ahead market and the support mechanism. The present study shows an affordable impact of the support scheme on the annual revenues of a wind plant for the period examined (years 2014-2015-2016), under the assumption that the strike value of the FiP scheme coincides with the fixed tariff of the FiT scheme. The annual income fluctuation for wind plants operating under different remuneration schemes were calculated to have a maximum value of ±1,5% per year, while for the total 3-year period the income variation does not seem to increase under the basic scenario.

6. Learning objectives

The present study proposes a methodology based on the use of mesoscale wind data and answers the question whether the change of the support scheme from FiT to sliding FiP in Greece creates significant uncertainty on the evaluation of the revenues of a windfarm. More calculations should be performed with longer periods of data and in other countries in order to better assess the accuracy of the energy production calculation and level of uncertainty. Moreover, the typical market obligations (e.g. balancing responsibilities) should also be taken into account per specific project in order to conclude a final investment decision.

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