Energies **2015**, *8*, 6497-6508; doi:10.3390/en8076497

OPEN ACCESS

energies

ISSN 1996-1073

www.mdpi.com/journal/energies

Article

Penetration of Photovoltaics in Greece

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Academic Editor: Tapas Mallick

Received: 30 March 2015 / Accepted: 16 June 2015 / Published: 26 June 2015

Abstract: Recently, an interesting experiment was completed in Greece concerning photovoltaic penetration into the electricity production sector. Based on the relevant laws and in accordance to the related European directives, an explosive penetration process was completed in less than three years, resulting in a 7% share of photovoltaics in electricity production instead of the previous negligible share. The legislation was based on licensing simplification and generous feed-in-tariffs. This approach transformed photovoltaic technology from a prohibitively expensive to a competitive one. This work aims to summarize the relevant legislation and illustrate its effect on the resulting penetration. A sigmoid-shape penetration was observed which was explained by a pulse-type driving force. The return on investment indicator was proposed as an appropriate driving force, which incorporates feed-in-tariffs and turnkey-cost. Furthermore, the resulting surcharge on the electricity price due to photovoltaic penetration was also analyzed.

Keywords: feed in tariff; return on investment; turnkey cost; renewable energy sources

1. Introduction

In compliance with the European "request" as a major environmental necessity and the related directives, laws intended to accelerate the penetration of renewable energy applications in the Greek electricity system were applied in Greece in recent years [1]. The Greek legislature had to adopt

legislative measures to format the framework of photovoltaics (PVs) penetration into the Greek energy mix. The legislation should have as objectives: (a) the formation of a considerable driving force for investment in photovoltaics and (b) the simplification of the existing administrative licensing procedure.

The main investment tools that international energy market has already developed are as follows: (1) investment subsidies; (2) subsided interest loans; (3) feed-in-tariffs; (4) feed-in-premiums and (5) green certificates, and the simplification of administrative licensing procedure could be integrated into the key stages of licensing.

Feed-in-tariff (FIT) was selected by the Greek government to motivate investments in PV. The FIT is the most widely used program to create incentives for the use of PV systems [2]. The related Greek legislation is summarized as follows:

(a) Law 3468/2006: Introduces generous FIT, but the licensing procedure remains complicated and time consuming.
(b) Law 3851/2014: Simplifies the licensing procedure and decreases FITs gradually even for already contracted projects.
(c) Law 4254/2014: Further decreases FITs even for old projects in operation on a retroactive basis. FITs for new projects are now related to the System Marginal Price (SMP or wholesale electricity price).

The effect of the above legislation on the penetration of PVs in the Greek electricity system is presented and discussed here. The main goal is to prove that a pulse-type driving force resulted to a sigmoid-type penetration response. Furthermore, the significant effect of the rapid penetration on the electricity cost is evaluated. A comprehensive analysis of the Greek legislation framework is initially presented and the quantitative impact of the legislation follows. It should be noted that present paper is an extended version of the paper presented in the WSEAS Dubai Conference 2015 [3].

2. The Evolution of the Greek Legislative Framework

The evolution of the Greek legislative framework of Renewable Energy Sources (hereinabove RES) is characterized by the following four phases: (i) premature evolution; (ii) euphoria; (iii) skepticism and (iv) reconsideration.

2.1. The Premature Phase

The Greek legislature recognized the necessity of RES penetration into the Greek energy map earlier than the greater European community. In the year 1971 Act 1044/1971 introduced power generation by PVs installed on kiosk roofs. In the year 1984 Act 1475/1984, the idea of power generation from RES was introduced by exploiting the geothermal energy potential of the country. In 1985, a new legislative initiative was taken, Act 1559/1985 gave auto producers the right to generate and utilize power from alternative energy sources.

In 1994, two important legislative events occurred. In the international context, the Climate Change Convention was adopted by the participant members states (ratified by Greece as Act 2205/1994), while in the national context the pioneering Act 2244/1994 passed, stipulating the right of private legal entities and persons to generate power from RES and sell it to public power companies using a uniform

and generous tariff basis, attempting to create a strong incentive towards RES penetration in Greek energy system [4].

Five years later, the necessity of a special spatial plan for RES was recognized as the potential answer to the decentralized and geographically diffuse character of RES development, due mostly to the plethoric insular relief of the country, by Act 2742/1999. In same year, Act 2773/1999 considered the infusion of energy from RES to the grid a priority for the first time. However, RES development did not proceed due to a) the lack of a special spatial plan for RES and b) the overcomplicated licensing procedure [5].

Two years later in 2001, the European Parliament issued Directive 2001/77, which supported rapid RES development for environmental protection reasons and required member states to adopt legislatives measures towards the stipulation of the State's financial assistance to promote investments in RES. Following the trend, in the same year, Decision C-379/98 of the European Union Court of Justice, recognized the considerable importance of RES to the protection of the environment. This decision has been the key pillar for the national legislative systems of European Union member states. It reinforced RES development in European Union by creating the legal platform upon which the State financial assistance is specifically recognized as legitimate, despite the provisions of European Union Convention articles 82 and 87.

2.2. The Phase of Euphoria

Directive EP 2001/77 was incorporated into Greek law by Act 3468/2006. The main objective of Act 3468/2006 is to support the unconditional connection of plants that generate power from RES to the grid. This Act resulted in the reconsideration of the grid status and the acceptance that grid should be invigorated and extended due to the geographically diffuse character of RES. The Act also set goals for Greece to meet by the year 2010, which were that the participation of RES in the yearly energy balance should not be less than 20%.

The second objective of the Act was to introduce a new pricing system for energy purchase agreements on a Feed in Tariff (starting from 400 €/MW basis and subsidy incentives by subjecting RES plants to the provisions of Act 3299/2004. Consequently, the interest of energy investors increased considerably, and a large number of investment plans have been implemented. Thus, Act 3468/2006 changed Greek energy policy dramatically by stipulating the Feed in Tariff system of RES energy pricing.

2.3. The Phase of Skepticism

In 2009, the European Directive EP 2009/28 was issued to create a uniform legislative framework for all European member states by setting higher goals to be met on the RES share of energy consumption. The introduction of the statistical transfer of energy and the development of joint projects by member states consortia were the main topics of this Directive towards the progression of RES development in Europe [6]. The above Directive was incorporated into the Greek legislative system three years later by Act 4062/2012.

In the meantime, Act 3734/2009 had been issued. It introduced the first considerable decrease of Feed in Tariffs, amending Act 3468/2006. As Table 1 shows, FIT decreased gradually on a semester

basis, starting in August 2009. It is important to emphasize that for the years that follow 2015, the FIT equals +30% or +40% (depending on installed power) of the average System Marginal Price (SMP).

Table 1. Evolution of feed-in-tariff (in €/MWh).

Year Month	National Grid		Insulated Islands
	>100 kW	≤100 kW	any size
2009 February	400	450	450
2009 August	400	450	450
2010 February	400	450	450
2010 August	392	441	441
2011 February	373	419	419
2011 August	351	395	395
2012 February	334	376	376
2012 August	314	354	354
2013 February	299	336	336
2013 August	281	317	317
2014 February	269	303	303
2014 August	261	294	294
2015 -	1.3 × SMP	1.4 × SMP	1.4 × SMP

Notes: SMP: System Marginal Price (Wholesale Price).

In 2010, Act 3851/2010 adopted the mandated European legislative framework national target for electricity from RES. Known as the rule of 20-20-20, the new national goals to be met were as follows: (i) 20% of consumed electricity should be generated by RES by the end of the year 2020; (ii) a minimum of 40% of the gross energy consumption should be contributed by RES; (iii) a minimum of 20% of the final energy consumption for heating and cooling should come from RESe; and (iv) a minimum of 10% of the final energy consumption for transportation should come from RESe. The second crucial objective of the new legislation was to simplify the licensing procedure and shorten the licensing time period. Thus, the large registered licensing queue was succeeded by a voluminous wave of construction. However, Act 3734/2009 adopted a mechanism of gradual decrease of FITs on a semester basis, a legislative initiative that resulted in new skepticism regarding the whole PV market, mostly by potential PV investors.

The simplification of the licensing procedure was significant. The role of the Regulatory Authority of Energy (RAE) was invigorated as it became the authority for RESe license issuance instead of the Ministry of Environment and Climate Change. Furthermore, under the new legislation, the issuance of a Decision for Environmental Conditions Approval is the most important prerequisite to achieve the Connection (to the grid) Offer. This change to the licensing process is important for two reasons. First, the legislature decided that Decision for Environmental Conditions Approval is a crucial stage of the licensing process without with the process cannot proceed. Second, by getting the Connection Offer, the applicant binds electrical space by ensuring a portal to the grid. According to new legislation, only projects that present a high level of licensing maturity could bind electrical space, leaving immature projects off the grid, avoiding the distribution of electrical space to projects that could never be fully licensed.

2.4. The Phase of Reconsideration

The high speed and pace of PVe penetration of the Greek energy mix, as analyzed above, caused an equally high pressure of liquidity demands regarding compensation for PVe producers. The liquidity gaps coupled with delay of relevant payments created a considerable deficit regarding special accounts for RES.

To resolve the liquidity issue, the Greek legislature should reconsider the RES penetration strategy and take steps toward the elimination of the deficit by taking measures that could ensure further rationalization of Feed in tariffs. The measures adopted at that phase fall into the following three groups: the first group aimed to cancel the PVe licensing procedure stipulated by MD F1/2300/16932/09-08-2012, given that the goal for year 2020 had been met in 2012. The second group aimed to decrease the Feed in Tariffs (by MD F1/2262/31.1.2012 and MD F1/16933/09-08-2012). The third group aimed to pass a part of the RESe cost to consumers by increasing the Special Fee of Greenhouse Gas Emissions (SFGGED). The RAE issued four decisions that gradually increased the SFGGED to 14.96 €/MWh.

Although the above measures intended to deescalate the deficit of PVe producer compensation, their impact on the issue has been minor. Therefore, a new legislative initiative has been undertaken. Act 4254/2014 stipulates a new decrease of Feed in Tariffs on a retroactive basis. Thus, small hydroelectric plants were subjected to an average decrease of 5.4%, wind plants, an average decrease of 5.6%, and PVe plants an average decrease of 29.9% of Feed in Tariffs.

3. The Quantitative Approach to Results of Legislative Initiatives

3.1. Photovoltaic Penetration in Greece

Figure 1 presents the effect of legislation on the penetration of PVs in the Hellenic electricity system, data from the Hellenic Electricity Market Operator (HEMO) [7]. The penetration is analyzed into two phases. (a) the licensing phase and (b) the construction phase.

Law 3468/2006 introduced generous FITs, as analyzed in the previous paragraphs, and a lot of applications for licensing was submitted to RAE [8] by investors of various magnitude.

Despite the large amount of applications very few licenses were issued due to the complicated licensing procedure and to exhaustive bureaucracy. The later explains why the following three years were passed without any significant activity (the licensing phase).

Instead, Law 3851/2010 simplified the licensing procedure and applied measures to accelerate it. Thus, a large licensing wave was appeared which followed by an analogous construction wave (the construction phase). Law 3851/2010 also decreased the FITs gradually *versus* the calendar year.

Finally, Law 4254/2014 further decreased the FITs even for old projects in operation in a retroactive basis. This sharp depression in FITs destroyed any further penetration, and the sigmoid penetration curve was completed.

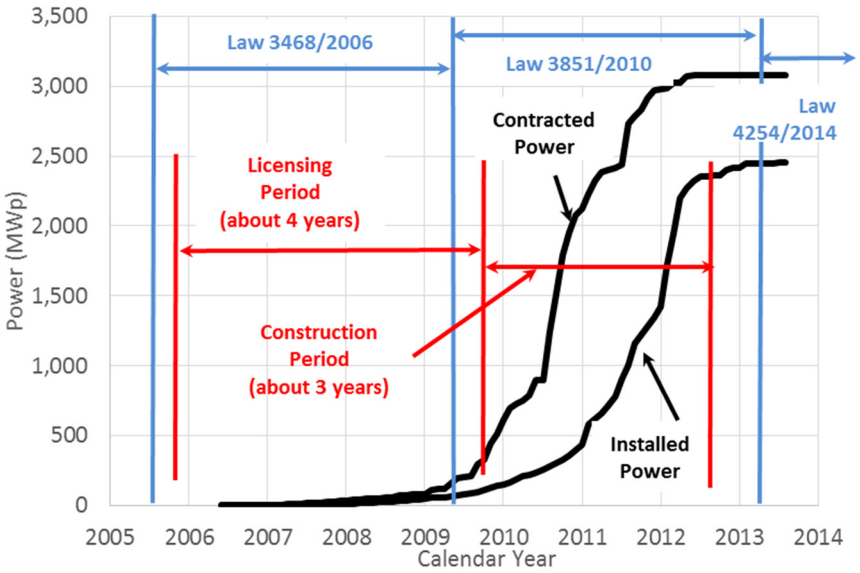

Figure 1. Photovoltaic Penetration in Greece. Data from Hellenic Electricity Market Operator [7].

3.2. Evolution of Feed-in-Tariff

Feed-in tariff was selected as the appropriate incentive by the government to motivate the investors. The three Acts described above affected the value of FITs over time as depicted in Figure 2. As analyzed in the paragraph 2, Law 3468/2006 was generous, but the successive 3851/2010 and 4254/2014 gradually depressed FITs to only 30% greater than the SMP. The electricity wholesale price is presented for comparison in Figure 2.

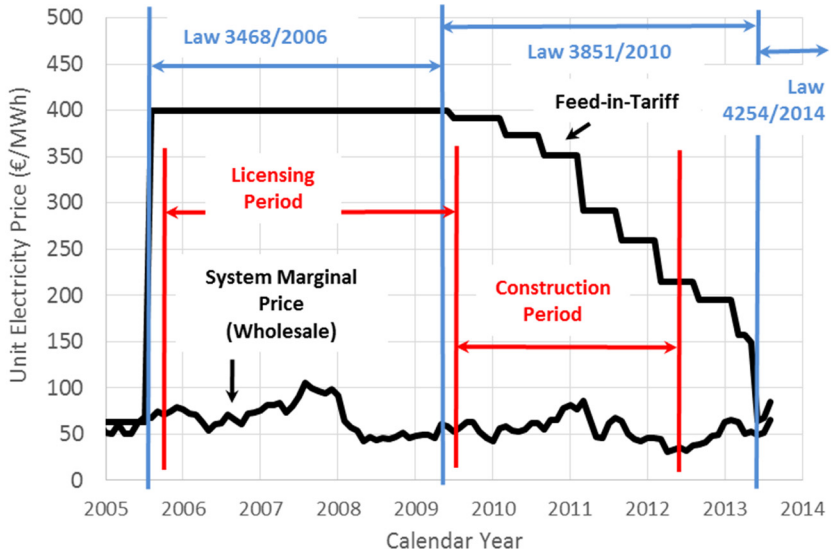

Figure 2. Evolution of feed-in-tariffs. Data from Hellenic Electricity Market Operator [7].

3.3. Evolution of Turn-Key Cost

Figure 3 shows the exponential equation that fits the published data concerning the turn-key-cost (TKC) of PV parks. The curve is a typical price-experience curve for Greece, which is similar to the

corresponding world-wide one. The data used comes from a study by the Hellenic Association of Photovoltaic Energy Producers (HAPVEP), which tracks the providers' Greek data and the Greek market construction characteristics [9].

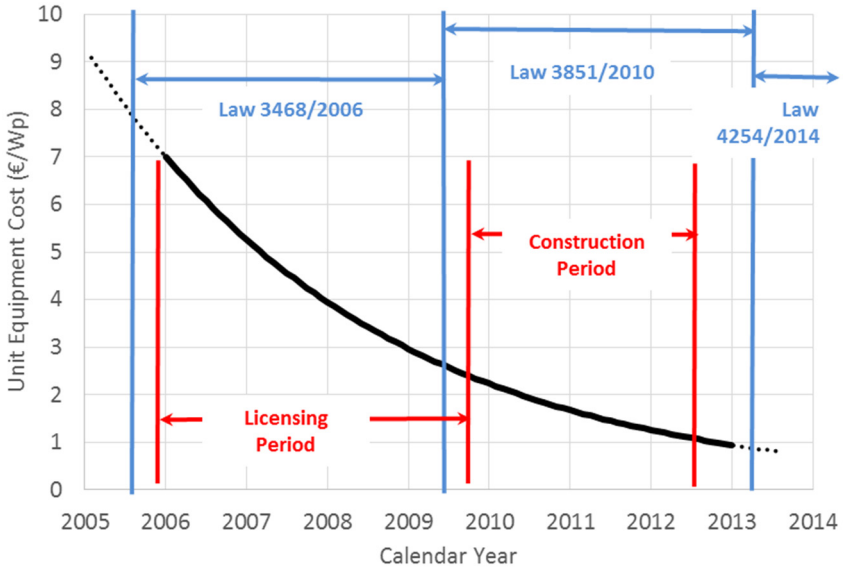

Figure 3. Evolution of Turn-Key Cost. Data from Hellenic Association of Photovoltaic Energy Producers [9].

3.4. Return on Investment Evolution

Because the penetration curve in Figure 1 is sigmoid, a pulse-type driving force is inferred. The FIT profile (Figure 2) selected by the government to motivate investors is one component of the driving force, the other is the TKC (Figure 3), as determined by the market. High values of FIT and low values of TKC are a good combination to motivate investing. An effective definition of a driving force should be taken into account these two magnitudes. In this analysis the Return on Investment (ROI) is considered as a driving force:

$$\mathrm{ROI} = \mathrm{FIT} \times \mathrm{PVY}/\mathrm{TKC} \quad (1)$$

where FIT (€/MWh) is the feed-in-tariff, TKC (€/MW) is the turn-key cost, and PVY (MWh/MW) is the annual park yield. The ROI as defined by Equation (1) is just an index to describe a driving force. It does not consider financing or operating cost, neither the time value of money, *etc*. [10,11]. Figure 4 presents the evolution of ROI *versus* time. It was calculated by Equation (1) using the data shown in Figures 2 and 3. The pulse type of the driving force has been proven. It should be emphasized that Figure 4 summarizes the history of PVs in Greece. Initially, before the Law 3468/2006 the driving force was negligible. A significant step-wise increment was suddenly appeared due to analogous increment in FIT. Then the driving force was started to further increase as TKC was gradually decreased.

By applying a systematic appropriate gradual reduction (in a half year basis) to FIT the driving force was stabilized, still in high level. These high values of ROI sustain significant investment until the FIT was decreased to negligible level.

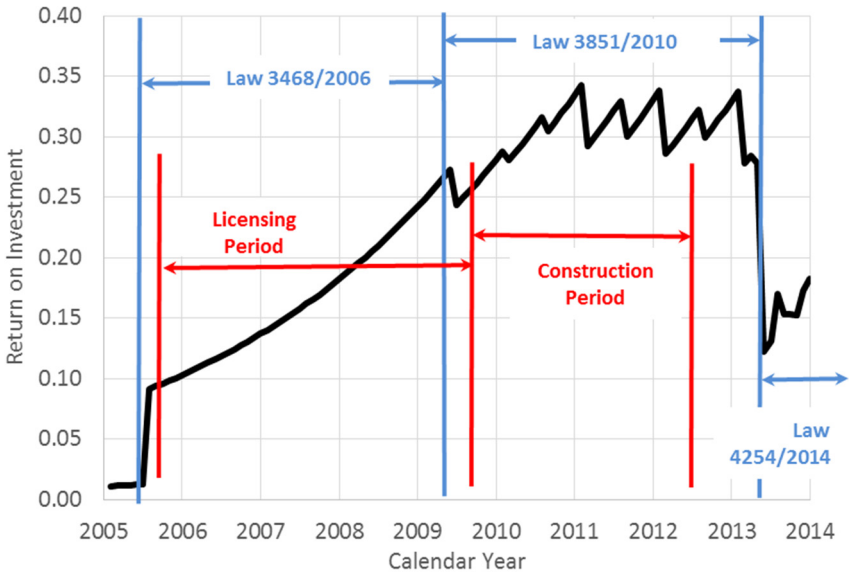

Figure 4. Return on Investment Evolution: An appropriate index to summarize the history of the driving force for PV penetration in Greece.

3.5. Electrical Energy Production

Figure 5 depicts the evolution of electricity produced by PVs as a result of the recent penetration in the Hellenic power system. For comparison, the 10% of the total electricity consumption is also presented. Both curves refer to monthly values in a moving average of 12 months in order to eliminate a seasonal effect.

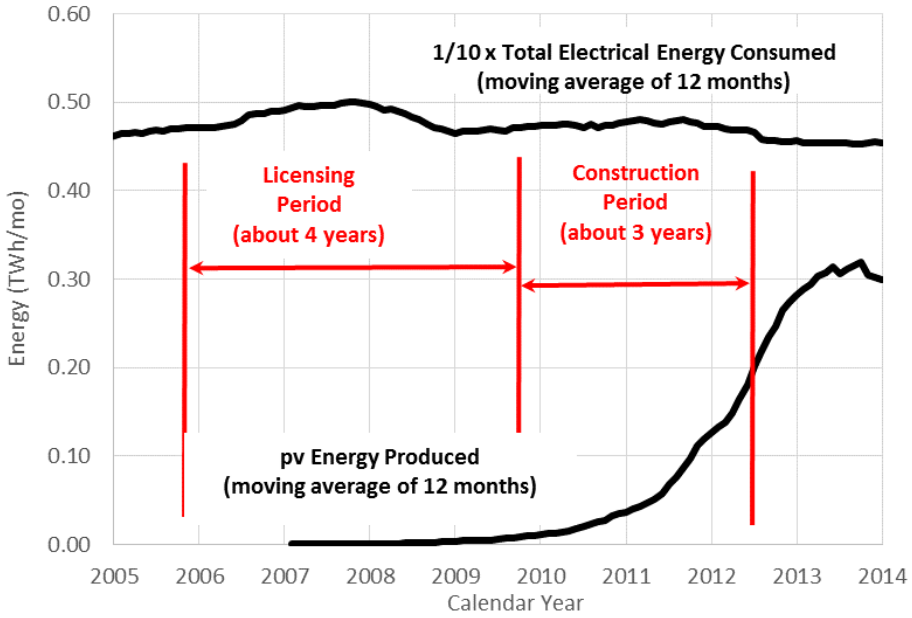

Figure 5. Electricity produced by photovoltaics. Data from Hellenic Electricity Market Operator [7].

It is concluded that after the construction years, the produced energy reached a steady-state situation corresponding to 7% PVs of the total consumption.

3.6. The Cost of the Feed-in-Tariff Incentive

Countries which adopted a FIT incentives accumulate a so called electricity tariff deficit [12]. It happens because the electricity market operator buys electricity from PV producers at the FIT and sells to electricity providers at the SMP. The deficit is borne by electricity consumers as a surcharge on retail electricity price. In Greece, this surcharge is called the "Special Duty of Greenhouse Gas Emission Deduction" (SDGGED), which is calculated by the following equation:

$$SDGHGED_{PV} = (FIT\text{-}SMP) \times E_{PV}/E \quad (2)$$

where FIT (€/MWh) is the feed-in-tariff, SMP (€/MWh) is the system marginal price, E_{PV} (TWh/mo) is the monthly energy produced by PVs, and E (TWh/mo) is the monthly electrical energy consumed (Figure 5). Actually an effective value of SDGHGED for all RES technologies is calculated by RAE at the end of every June and December for each year. Instead, Equation (2) calculates the exact contribution of PV to SDGHGED in a monthly basis. Figure 6 compares the resulting FIT paid by the electricity market operator to PV producers with the SMP (wholesale price).

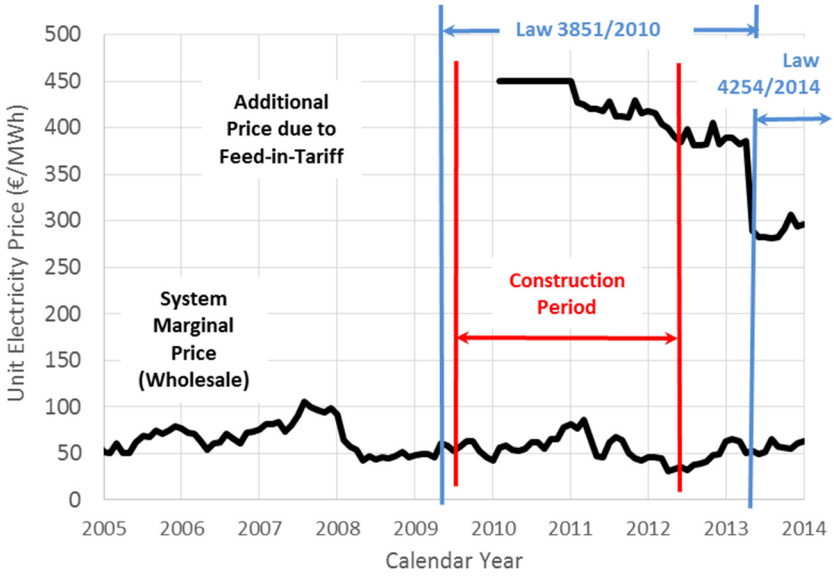

Figure 6. Feed-in-tariff and system marginal price evolution. Data from Hellenic Electricity Market Operator [7].

This difference is very significant because it creates the above deficit. It should be noted that Figure 2 depicts the valid FIT during the time, which could be obtained by a project contracted and constructed during that time. Instead, Figure 6 presents the average FIT for all the projects in operation as they are paid by the HEMO. It is the current mixture of different values obtained in different times in the past. Figure 7 compares the resulting surcharge to electricity consumers due to the cost of PV incentives with the SMP. A significant observation is that when the "penalty" due to FIT is important an analogous reduction of SMP occurs. This phenomenon is known as "merit order effect" [13].

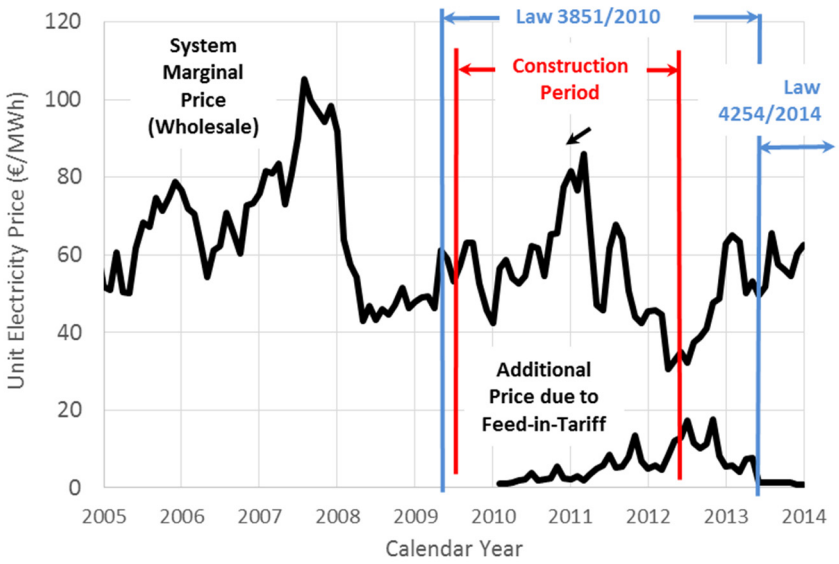

Figure 7. Comparison of surcharge of photovoltaic incentives to electricity consumers with the system marginal price.

4. Conclusions

As the above analysis reveals, an interesting experiment concerning the PV penetration in Greece was completed recently: In compliance with the European "request" for accelerated penetration of RES in the Greek energy mix, the Greek legislature and regulatory agency adopted administrative measures that motivated a large number of investors to implement PV projects.

The legislation applied by the Greek government was based on licensing simplification and feed-in-tariffs application which resulted to a total installed capacity of 2.5 GWp producing about 3.6 TWh per year which corresponds to about 7% of the annual total electricity consumption.

The penetration exhibited a sigmoid-type profile which could be explained be a pulse-type driving force. The suggested ROI index as a driving force proved adequate since it corporates two crucial magnitudes, the FIT measure regulated by the government and the TKC regulated by the PV market.

Initially the FIT was generous but since the TKC was changed an analogous adaptation to FIT were decided, resulting to a sudden sigmoid deployment of PVs, despite to linear deployment of wind energy projects.

In conclusion, at the moment the PV penetration in Greece has stopped, but if the policy makers wish to continue penetration with a controllable way the ROI indicator should be used, that is taking into account the current TKC the regulation of FIT should be so as the ROI be kept to a reasonable desired level.

Author Contributions

This is a partial fulfillment of Eugenia Giannini's PhD degree supervising by Zacharias Maroulis. Antonia Moropoulou and Glykeria Siouti are technical and legal advisors, respectively.

Conflicts of Interest

The authors declare no conflict of interest.

Abbreviations

FIT	Feed-in-Tariff
HAPEP	Hellenic Association of Photovoltaic Energy Producers
HEMO	Hellenic Electricity Market Operator
RAE	Regulatory Authority of Energy
RES	Renewable Energy Sources
ROI	Return on Investment
PV	Photovoltaics
PVY	Annual PV Park Yield
SDGHGED	Special Duty of Greenhouse Gas Emission Deduction
SMP	System Marginal Price
TKC	Turn-Key-Cost

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