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Economic Assessment of DM 2019: the Italian Policy for the Photovoltaic Generation

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ABSTRACT

This work presents an economic assessment of the most recent Feed-In Tariff in Italy, called DM 2019. As a first stage, the historical results from the previous DMs was presented, to understand the policies influence in the increase of photovoltaic (PV) projects. The DM 2019 contains the relevant technical information and the grant process to support determined PV plants; based on this guidelines, two theorical plants with strategical sizes are proposed. The economic assessment is made through the Levelized Cost of Energy (LCOE) methodology and the remuneration approach presented in the policy, in which are involved different types of Tariffs.

Finally, the results and conclusions expose the advantages and drawbacks of the DM 2019, taking in consideration the technical and economical characteristics of the plants.

LIST OF FIGURES

LIST OF TABLES

Contents

1. INTRODUCTION

1.1 Context

The injected energy to grid from Solar photovoltaic (PV) systems has had a significant growth during the last decade in Europe, mainly as a consequence of two factors: decrease in the installation cost (production and sell of the PV units) and stimulant policies to convert the PV energy into a profitable business.

Among these policies, the Feed-In Tariffs (FIT) have become the best instrument to lead the solar energy market towards a consolidation into the internal mix in countries as Germany or Italy, reaching important quantities of installed power.

The FIT policy was developed as an internal program in each EU country with differences in performance but with the same target; in Spain the system collapsed and was necessary to stop it, leaving the investors in a uncertainty risk scenario looking ahead; in others countries as Germany, the program was and still is in constant revision and updating it, to suit the recent internal conditions.

Some authors have claimed that the grid-parity has been achieved in determined systems and is no longer necessary to have these kinds of policies to benefit the PV generators and it's time to let them interact in a free market, therefore the PV market revenues will depend in the way that the incumbents can compete without the government helps.

Nevertheless, there's no guarantee that the PV market can subsist yet without the assistance, on the contrary some authors have showed that the decrease in the FIT amounts have decelerated the investments in renewable energies.

Thus far in Italy were applied five Decrees to regulate the payment mechanism starting in 2005, the cap was reached by 2013 and let the new plants attached to a contract of 20 years where is guaranteed the purchase of their solar energy.

Under this scenario a sixth Decree was launched to update the incentives status for PV sources: the DM 04/06/2019; in which are presented new considerations and the incentive prices have been updated.

1.2 Objetives

- To comprehend the influence of the Feed-In Tariffs policies in the photovoltaic generation in Italy.
- To evaluate the advantages and limitations of the remuneration process contained in the VI *Conto Energia* (DM 04/06/2019).
- To assess the economic viability of PV projects through the LCOE methodology and the Tariffs presented in the DM 2019.

2. POLICIES TO INCENTIVE THE PV GENERATION IN EU

With the adoption of the Renewable Energy Directive (2009/28/EC) in 2009, for the first-time renewable energy targets for all EU member states have become effective by 2020. The overall European Union (EU) target is a 20% share from renewable energy sources (RES) in the final energetic consumption in 2020, as set in the 2008 decided package of energy and climate change legislation of the EU [1].

Among the different kind of policies available into the EU region, the most used for the RES are [2]:

- Feed-in tariffs (FIT)
- Feed-in premium (FIP)
- Quota obligations with tradable Green Certificates

Figure 1 shows the use of the incentive instruments by country, the combined colors mean a mixed among the policies.

In Green Certificates mechanism, governments fix quantities and the market decides the price. A minimum share of the electricity supply has to be from RES, and this share is increasing over time. Suppliers may trade certificates for electricity from RES if they cannot reach the minimum share with own production [1].

FIT and FIP policies match better with the PV technology prospective, due the fact that Green Certificates limit the production to a specific quantity of energy. That's the reason why FIT and FIP are been more used along the time to the PV plants, and that's why the work is going to be focused specifically in these two policies.

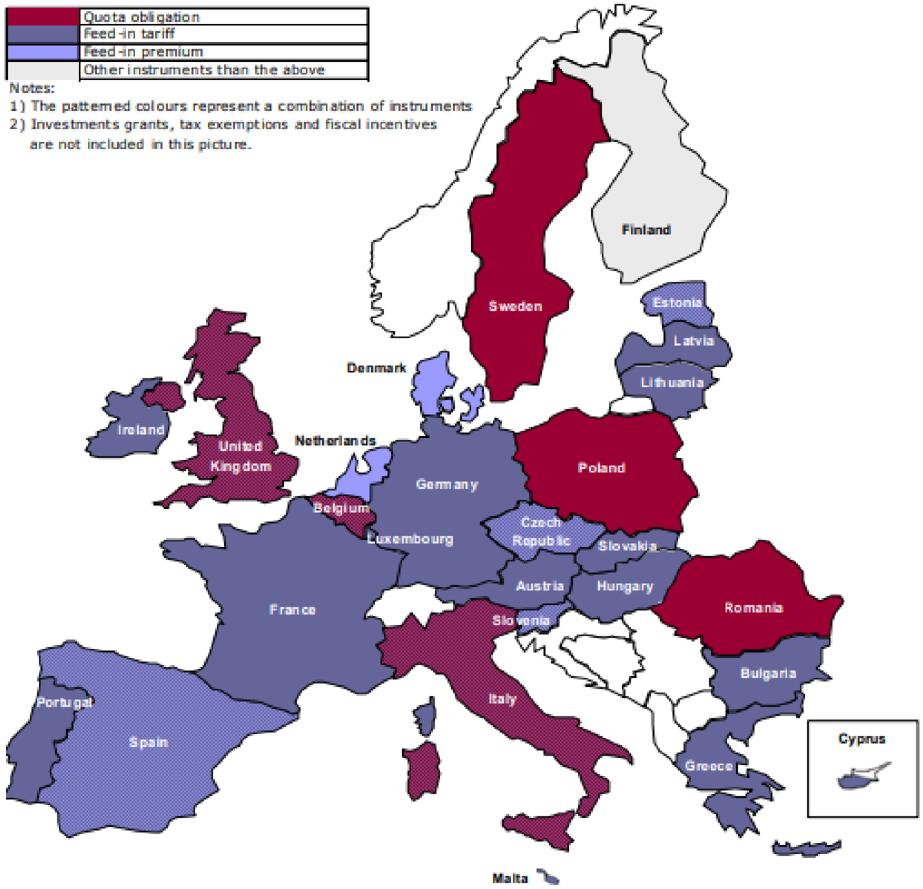

Figure 1.Main Support Instrument for RES [2]

2.1 Feed- In Tariffs and Premiums for Solar Photovoltaic Energy: Situation in EU

The Feed-In Tariffs (FIT) are policies created to promote the installation and development of different types of renewable energies, the incentive focuses on guaranteeing a long-term contract for the generators with a specific remuneration through the project life. This economic policy can be classified as a based on prices, because the energy price is a constant along the time; as a counterpart the Green Certificates are a based on quantity policy, where a specific market is created to trade a minimum quote of renewable energies, as any market the prices depend of the current market forces.

Even if it is not the only mechanism used in Europe, the FIT have been a well spread financial tool to promote the solar energy development, that's due to the fact of giving a safe environment, where the investors know the payments in advance and can forecast cash flows scenarios based on the expected energy generation, associated cost and technical losses. Usually FIT are implemented with additional economic schemes such as auctions or prices classification in order to create an entire law regulation.

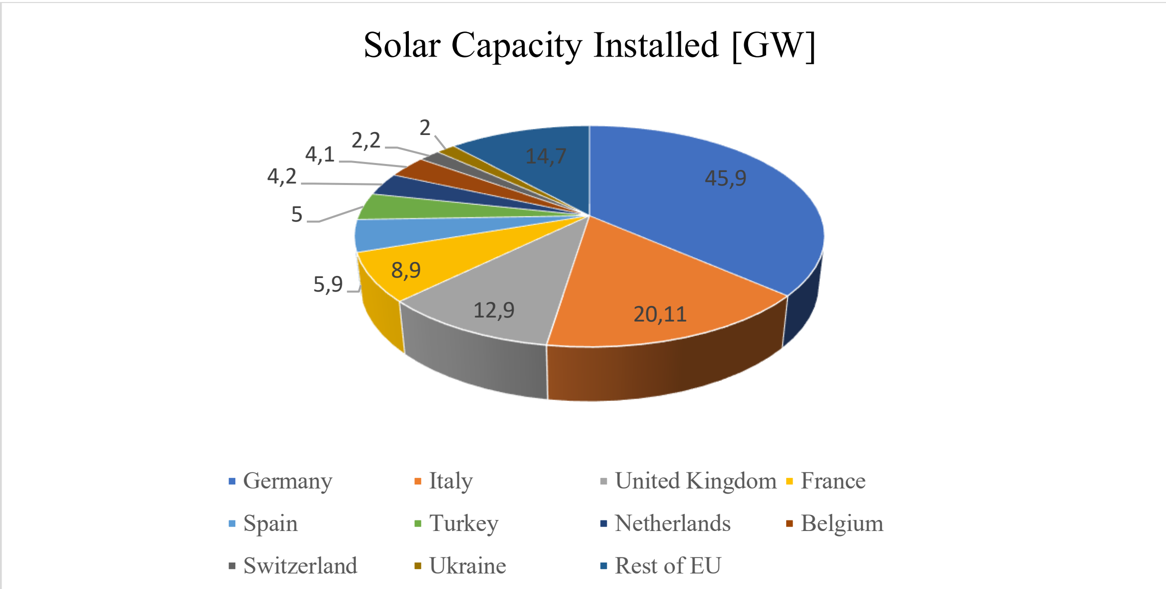

Figure 2. Accumulated Installed Solar Capacity in 2018 [3]

In the Figure 2 is showed the top ten European countries with more solar capacity accumulated in 2018. With an additional installation of 11,2 GW, the total amount counted until 2018 is 125,8 GW around Europe; this represents an increase of 21% with respect to the year 2017. In Table 1 are showed the policies in force in the main European countries for the solar energy development; it's possible to observe that Feed-In Tariffs appear in each country with exception of Spain, where the FIT were suspended in response to a financial crisis.

Table 1. Policies by Country [4]

Country	**Type of Support**	**Duration of Support [years]**
Germany	Feed-In Tariffs Feed-In Premium	20
Italy	Feed-In Tariffs Feed-In Premium	15 to 25
United Kingdom	Feed-In Tariffs Feed-In Premium	10 to 20

	Green Certificates	
France	Feed-In Tariffs Feed-In Premium	10 to 20
Spain	Investment Grant	20 to 30
Netherlands	Feed-In Premium	8 to 15
Belgium	Feed-In Premium Green Certificates	10 to 20

The Feed-In Premium (FIP) are agreements that allow to have an extra remuneration taking as a reference the spot electricity market, FIP can either be fixed or floating. Fixed FIP are simpler in design but there is a risk of overcompensation in the case of high market prices and of under compensation in the opposite case. FIP scheme appears as an evolution of the FIT, due mainly because of the decreasing generation costs in the solar technology; it can be said that FIT serve to set a specific price and from there stablish the FIP with floor and cap limits.

As can be seen FIT and FIP are both the preferred policies among European countries and their continue reviewing and adjusting it's a vital importance for the solar market consolidation; according to the Global Market Outlook for Solar Power 2019-2023 [3], even under low estimations, the target it's to install yearly an additional amount higher than the one referenced in 2018.

To meet this goal and being in concordance with the 2030 Global Plan, the correct implementation of mentioned policies is the key success factor to ensure satisfactory economic indicators for the investors.

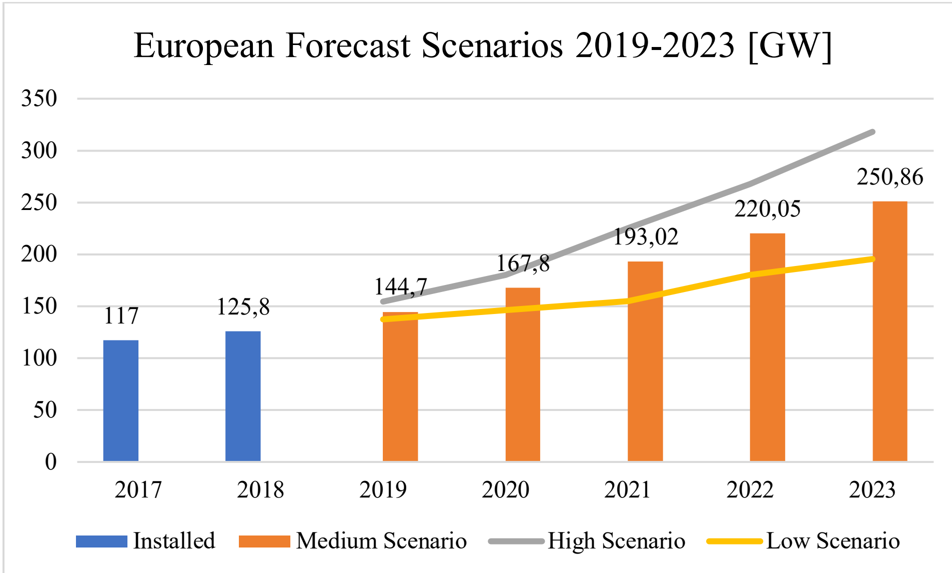

Figure 3. Expected Installed Capacity in the EU [3]

2.2 Feed- In Tariffs and Premiums for Solar Photovoltaic Energy: Situation in Italy

2.2.1 Results from I Conto Energia to V Conto Energia: Outlook 2005 - 2012

The Italian government through the *Gestore Servizi Energetici -GSE* (Energy Services Manager) begins in the year 2003 an important plan to boost the renewable energies into the country; but is only until 2005 that took effect the Decree of the Ministry of Economic Development and was finally created the operative legislation with the name of *Conto Energia* (Energy Bill) [5]. Along the next seven years the *Conto Energia* was changed in terms of technical specifications, plants typologies and benefits.

According with the GSE [5]; the main objectives of the *Conto Energia* were:

- To promote a higher contribution from the renewable sources to the electrical generation in the Italian market.
- To promote proceedings to follow the objectives of the Decree.
- To contribute to the creation of a common base according with the Decree specifications.

- To promote the development of microgeneration electric systems supplied by renewable sources, mainly for the countryside zones.

Even if the scope of the *Conto Energia* has included several types of generations, such as: on shore wind, off-shore wind, biomass, geothermal, etc; was the solar photovoltaic technology that took more advantage from the incentives and got an exponential growth along the country and basically have been installed plants in each Italian town.

The five changes of the *Conto Energia* are enumerated as follows [5]:

- DM 28/07/2005 – I *Conto Energia*
- DM 19/03/2007 – II *Conto Energia*
- DM 06/08/2010 – III *Conto Energia*
- DM 05/05/2011 – IV *Conto Energia*
- DM 05/07/2012 – V *Conto Energia*

It's important to point out that each DM must be treated as a law itself, this means that first *Conto Energia* was basically the base paper to set the rules and specifications for the second DM and even some principles have been maintained during the years, at each time the standards are updating and have relevance to enforce the new projects, but those do not change the framework for the past projects.

DM 2005 allowed to receive the benefits to those plants with nominal power between 1 kW-1000 kW; the nominal power is the power indicated in the solar cells provided by the fabricator, it is not necessary related with the maximum or medium energy that actually can be delivered. In this Conto Energia, the classification was divided in two groups; plants under 20 kW, and over 20 kW; and was not a clear reference to the systems typology installation [6]. According to the legislation it is clear the DM 2005 had a strong favorable framework, because was based mainly in high prices, but it had lack of detailed installation specifications, which is normal according to the year and taking account that was the first important law promulgated from the government.

The DM 2007 made a distinction between the integrated and not integrated PV plants, and basically promoted the domestic installation of solar solutions [7]. The integrated plants commonly named as BIPV (Building Integrated Photovoltaic) allowed the use the roofs for energy production, even in small quantities in comparison with the no integrated systems, BIPV have some technical benefits and give energetic complementary to the households. The systems could also be partially integrated, the difference is showed in the Figure 4.

Figure 4.Totally and Partially Integrated PV [8]

From the II *Conto Energia*, every installed plant earns two kind of benefits: one, called *Tariffa Incentivante* (Incentive Tarriff), which is granted to the energy produced from the PV plant; and the second, called *Energia Scambiata* (Exchanged Energy), granted to the energy actually delivered to the grid [9].

The values of the Incentive Tariff are showed in the Table 2, it's possible to appreciate the diminishing prices at each time and according to the PV typology. Due the fact that integrated systems may carry along higher costs, the incentive prices are also higher. The continuous reduction of the revenues is 2% per year [9].

The discrimination prices according with the typology of PV plants had a huge effect, reflected in the fact that 93% of the projects in the DM 2007 were totally or partially integrated [5].

Table 2. Prices in the II Conto Energia [9]

Revenues According the PV Typology in the II° Conto Energia				
Power	**Year**	**Non Integrated [€/kWh]**	**Partially Integrated [€/kWh]**	**Totally Integrated [€/kWh]**
$1 \leq P \leq 3$	2008	0,400	0,440	0,490
	2009	0,392	0,431	0,480
	2010	0,384	0,422	0,470

3 < P ≤ 20	2008	0,380	0,420	0,460
	2009	0,372	0,412	0,451
	2010	0,365	0,403	0,442
20 < P ≤ 6000	2008	0,360	0,40	0,440
	2009	0,353	0,392	0,432
	2010	0,346	0,384	0,422

DM 2010 was applied from 31/05/2011 and were stated specific tariffs for integrated PV with innovative characteristics and concentration PV systems [5].

DM 2011 defined the mechanism to the systems that started to work after 31/05/2011; a budget limit of 6'000.000 € was established [5]. Among the main features of the DM 2011 it's possible to name the fact that was set a yearly annual limit cumulated of PV plants that could have access to the incentive tariffs, and have in consideration the decreasing costs of the technology to define the incentive tariffs [10].

Finally, the DM 2012 settled the cumulative cost equal to 6'700.000 € [5]. Besides of the incremented budget, the Decree presented a higher flexibility in the thresholds for the register of the projects and enlarge the definitions of the PV resources, such as: integrated innovative PV systems, concentration systems, PV systems built by public administration, etc. An extension of the incentive to the rural fabricators, specific prizes, with simultaneous reduction of the basic rates, for certain categories of systems with modules installed on buildings in replacement of asbestos roofing, as well to installations with main components manufactured in Member States of European Union [11].

Through the description presented it's possible to conclude that the Conto Energia methodology benefits itself from the cumulative experience; and the updates have tried to include and stimulate every time a broader number of PV typologies installation, PV technologies and kind of investors.

The duration of all *Conto Energia* incentive is 20 years, during this time the remuneration is constant, no matter the updates in the Decrees. After 20 years the producer has two options, to benefit from Net-metering or selling the energy to the grid [12]. Table 3 shows the results in terms of installed capacity for each *Conto Energia.*

Table 3. Results of the five Conto Energia [12]

Decree	Number of PV Plants	Installed Power [MW]
I Conto Energia	5725	163,431
II Conto Energia	203766	6791,404
III Conto Energia	38603	195,626
IV Conto Energia	202189	7554,185
V Conto Energia	30305	477,186
Total	**480588**	**15181,832**

According with both, number of PV plants and installed capacity, the II and IV Conto Energia were the most effective Decrees, achieving most the 90% of the incentive solar energy.

Taking as reference the 2013 as the year where the cumulative cost of 6,7 billion of euros was reached [5], the total the installed capacity were equal to 18185 MW, which represents around the 90% of the total accumulated capacity by 2018; it is clear the huge effect of the policies in the solar market development. Indeed, the tendency after 2013 shows an increasing performance in number of PV plants, but almost flattened in the installed capacity.

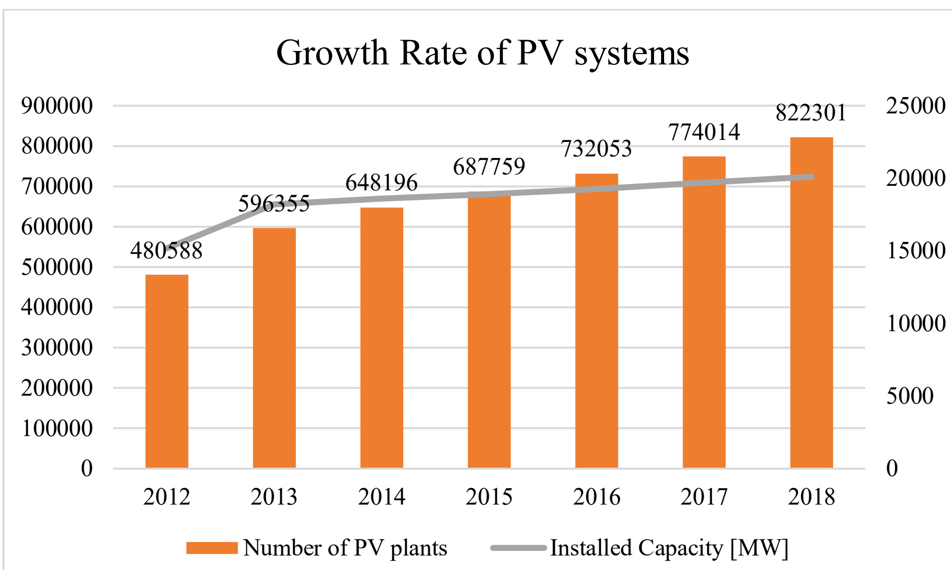

Figure 5. PV Installed Capacity after the V Conto Energia [13]

As it's showed in the Figure 5, the number of PV systems from 2012 have increased more than 70%, although in the other hand the installed capacity reached only a growth around 30%; moreover since the CAP was reached, the installed capacity only have evolve 10% in five years. This only can mean that the new PV systems are represented in low power nominal plants, mainly integrated over roofs, buildings and shelters.

As a visual aid, Figure 6 presents the map of Italy registered according the number of PV plants installed, the evolution is remarkable, and it was worth to Italy to be the only one among the principal European countries that reached its goal of using 17% of the energy produced from renewable sources by 2020, according to the Directive 2009/28/CE [1].

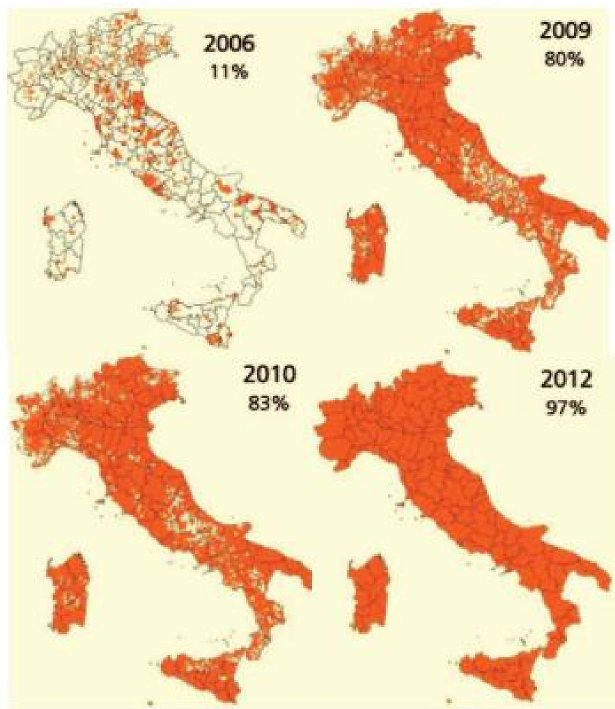

Figure 6. Penetration of Incentived PV plants [12]

In Figure 6 the red zones corresponds to the towns were are located at least one PV system; basically the coverage of the national territory was in the 2012, and by now in 2019 its accounted as 100% of the country.

It's useful also to know the PV distribution for capacity and energy produced by region, because the Italian electrical market defines different prices for the spot market according to geographic zones.

Although the South region presents better radiation indexes along the year [13], more concentration of power installed is located in North; with exception of Puglia where are performing several big scale parks, Figure 7. This is corroborated in terms of energy production, where Puglia has lead the ranking regions with more than 15% of the national solar generation, Figure 8.

Figure 7. Distribution of Installed Capacity by Region [13]

Figure 8. Energy Production by Region [13]

According to the discussion presented in [12], the commercial relationship between the producer and the Utility, data collected highlight that in the five *Conto Energia*, most of energy produced from PV plants has been sold in order to have a direct profit from the fees; this is of a special interest because states a clear efficacy of the Feed-In Tariffs as a financial support to develop to solar market in Italy.

The mechanism of *Conto Energia* changed radically the distribution system in Italy [12], with different technical implications, the distribution passed from been composed by few medium/high power plants to a system made of several little/medium power plants, in only 7 years.

Table 4 shows the plants installed by size until the date of 31/12/2018; plants until 20 kW represents the 20% of the total installed. The main indicator of this performance is the increasing share of use of urban spaces for local generation and an important perspective to the self-generation from the households' side.

Table 4. Distribution of PV plants by Size [13]

PV size	Number of plants	Power Installed [MW]
$1 \leq P \leq 3$	279681	759,8
$3 < P \leq 20$	476396	3445,2
$20 < P \leq 200$	54209	4244
$200 < P \leq 1000$	10878	7413,2
$1000 < P \leq 5000$	948	2328,2
$P < 5000$	189	1917,2

Finally is useful to say that most of PV plants are owned by companies, although it's interesting to highlight the conclusion in the paper [12], which states that "*thanks to the FIT Decrees, some banks have financed people for the installation and the use of a PV plant. In returns, banks have received the FIT incentives until the debt is paid from the end-user.*"

2.2.2 VI Conto Energia – Outlook 2019

Thus far, has been presented a summary of the main features and results of the five *Conto Energia* in Italy, in this subchapter are going to be listed the main characteristics of the DM 04/06/2019 (in follow referred as DM 2019) corresponding to the VI Conto Energia.

DM 2019 will be the technical and economic reference for the incentive calculations in the next chapters. First that all it's necessary to mention that the Decree issued by the Government is only a document, where is expressed the law itself to promote a broad framework for the next 20 years of PV projects environment; then the GSE created several documents to organize the whole information and precedents for the execution of the projects.

The two most relevant DM 2019 documents for the thesis proposal are *Regolamento Operativo per l'inscrizione ai Registri e alle Aste* (Operative Rule Book for the Inscription and Register to the Auctions) and *Regolamento Operativo per l'accesso agli Incentive* (Operative Rule Book for the Access to the Incentives) [14] [15].

The main points of these Rule Books to the PV plants are listed as follows:

- PV plants must be exclusively of new construction, it means, that all the components are required to be of new acquisition and the minimum power to be installed is 20 kW.
- There are two kind of incentives: the first one is called *Tariffa Incentivante Omnicomprensiva - To* (Comprehensive Incentive Tariff) and the second Incentivo – *I* (Incentive), which is the difference between a fixed value and the hourly zonal price of the energy (the zone makes reference where the energy is injected to the grid).
- Plants until 250 kW can opt for any of the two tariffs and may change twice their decision along the incentivized period.
- Plants with power over 250 kW can have access exclusively to the Incentive (I)
- For the Comprehensive Tariff case, the amount paid corresponds to the energy produced and injected to grid. For the Incentive case the energy is related to the producer availability.
- Both Tariffs are subjected to the definition of other three tariffs, which are: *Tariffa di Riferimento* (Reference Tariff), *Tariffa Offerta* (Offered Tariff) e *Tariffa Spettante* (Relative Tariff).
- Besides, the DM 2019 includes two combinable premium incentives, the first one for the registered and selected PV, installed to replace roofs of buildings and rural buildings on which the complete removal of eternity or asbestos is carried out. And the second one to the energy produced and self-consumed, if this is more than 40% of the net energy generated for plants with a power below of 100 kW.

Table 5. Reference Tariff for PV plants [14] [15]

Group	**Typology**	**Power**	**Useful Life**	**Reference Tariff**	**Premium**	
					PV Group A-2 with P < 1000 kW	**PV over roof buildings for self-consume, with P ≤ 100 kW**
		[kW]	**[Years]**	**[€/MWh]**	**[€/MWh]**	**[€/MWh]**
Group A		20 ≤ P ≤100	20	105		10
		100 < P < 1000	20	90		
		P ≥ 1000	20	70		
Group A-2	replace of buildings roofs to remove eternity or asbestos	100 ≤ P < 1000	20	105	12	10
		P ≥1000	20	90	12	

Table 5 shows the PV typology plants and their correspondent prices according with the Reference Tariff.

In Table 5, the group refers to the place where the plants are installed, because to the group A belongs other than PV, the wind farms. It's possible to see that the tendency of DM 2019 is consistent with the precedent *Conto Energia*, because it considers a discrimination fee according to the power size.

- From the technical point of view, DM 2019 defines the power of a PV plant as the sum of the single nominal power of each PV module integrated in the same system.
- DM 2019 allows to be in consideration for the incentive the "aggregated power", which is a sum of more than two PV plants located in different geographic points that belong to the same owner, as long as each plant counted by 20 kW and the total sum no more than 1000 kW.
- DM 2019 acts according to an auction mechanism, setting the next power quantities for each procedure.

Table 6. Power Quotes in the Auctions [14]

Procedure N°	Group A [MW]	Group B [MW]	Group C [MW]
1	500	5	60
2	500	5	60
3	700	10	60
4	700	15	60
5	700	15	80
6	800	20	100
7	1600	40	200
TOTAL	**5500**	**110**	**620**

In Table 6, procedure means the date when the project is registered, there are 7 register dates between 2019 and 2021. The Group A column includes the both typology of PV plants and wind farms.

- The final list from the procedures in the auction will be establish in base of the Reduction Tariff presented by the investor.

- The access to the any of the both incentives for PV plants are exclusively for total new projects. It means that any modification, intervention, reconstruction, reactivations, power expansion or remake on already installed PV plants are excluded from the benefits.
- The PV panels not installed in roofs or buildings structure must be installed only in lands not destinated to agriculture functions.

The technical treatment and calculation methodology mentioned in the DM 2019 will be considerate in the next chapters.

3. METHODOLOGY

The economic viability of a PV plant according to the current situation in Italy, should follow the next simplified explained methodology:

- Compute all the costs involved
- Compute the revenues perceived
- Assess the cash flows to define specific indicators as VPN.

In the costs section must be considered installation, maintenance and capital expenditures according to the capacity in power of the project. From the revenues point of view, the values and percentages are defined in the DM 2019 and are related to the source, typology and execution time.

Both calculations are strongly associated to the energy generated, which at the same time depends on the capacity and external conditions as: location, technology and electrical parameters; for that reason in this chapter is going to be explained in detail the calculation methodology for generic projects; the goal is to define a standard process in which is possible to variate only some parameters to obtain the specific indicators according to the nature of the project.

3.1 The Levelized Cost of Energy – LCOE

A well spread and useful methodology to compute the cost of the energy generation is The Levelized Cost of Energy (LCOE); the LCOE contemplates the different kind of project costs and gives as return a monetary value per energy unit. Among the advantages of LCOE are the consideration of the lifetime projects, the inclusion of different classes of costs and the connection with technical parameters associated to the energy produced.

With the LCOE is possible to compare different sources (not only renewable) of unequal life spans, project size, different capital cost, risk, return, and power capacities. For these reasons is the most used tool to make-decision of an energetic project implementation.

In a very simplified calculation, the LCOE can be defined according to the next equation:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{CAPEX_t + OPEX_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Equation 1

Where:

- $CAPEX_t$ is the capital expenditure cost, it is the initial investment.
- $OPEX_t$ is the maintenance and operational costs
- F_t is the fuel cost
- E_t is the energy produced
- r is a discount rate
- n is the life span of the project

Equation 1 is the LCOE calculation base for any source, it can be adapted and go to a more detailed version according with the study approach. For PV systems, the drivers of LCOE are CAPEX and the Energy Produced.

CAPEX is a driver because PV systems don't have fuel costs but important initial investments in panels, inverters, installation and grid connection; in the other hand the Energy Produced is associated to the so-called Capacity Factor (CF); the CF is the rate between the actual energy production of the plant and the energy that could be produced according to the installed capacity, it's a measure of how much energy is produced by a plant compared with its maximum output.

As the energy produced by a PV plant depends on the solar radiation, the appropriate estimation of the CF is a key issue for the project's viability. The CF of PV plants can vary in a considerable range of values usually from 10 - 25%.

Another approach is to use the yield given by the relation kWh/kWp/year; this unit is used mainly by the industry sector to point out the potential energy yield (kWh) per installed capacity (kWp) and is site dependent.

Even the CAPEX and CF relevance, discount rate (financing costs) and annual operating expenses are a non-trivial issue; in fact some studies as presented in [16], shows the importance of the rate definition; in [16] is presented a sensitive analysis of the PV plants according to the balance between a Debt and Equity setting the Weighted Average Cost of Capital (WACC) as the rate.

Modifying Equation 1 for PV plants, the work in [17] presents the LCOE evolution for PV plants in the south of Italy.

$$LCOE = \frac{OCS \times CRF + FO\&MC}{\frac{E_0}{N} \sum_{t=1}^{N} \left(1 - \frac{d_r \times (k-1)}{100}\right)}$$

Equation 2

Where,

- OCS is the overnight capital cost of the plant
- CRF is the capital recovery factor
- $FO\&MC$ are the fixed operation and maintenance costs
- E_0 $[kWh/kWp/year]$ is the productivity of the plant when is installed
- d_r $[\%/year]$ is the degradation rate of the PV modules

$$CRF = \frac{i \times (i+1)^N}{(i+1)^N - 1}$$

Equation 3

In Equation 2, CAPEX and CF are represented in the overnight cost and productivity of the plant, while the rate is represented in the CRF through Equation 3.

The work in [17] includes the panels degradation, affecting the total energy produced; the parameters in time, energy yield, CRF and degradation were set according to the National Survey Report of PV Applications in Italy, whose reports are produced once per year by national PV experts [18].

The results of the work is shown in the Figure 9, where an important drop in the LCOE can be appreciated through years; results are presented until year 2016 for the south region of Apulia reaching a cost around of 51€/MWh.

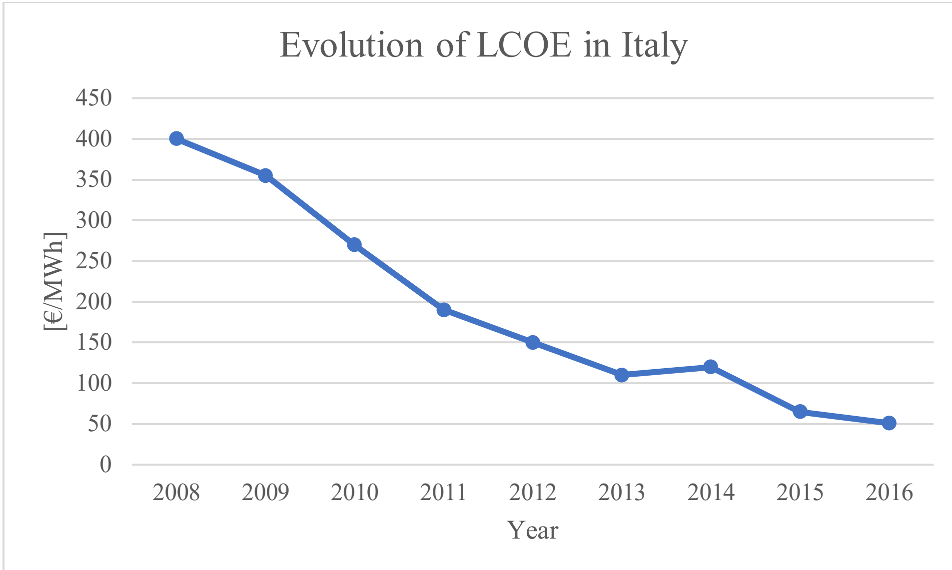

Figure 9. Evolution of LCOE in Italy [17]

The LCOE in [17] does not have in consideration the connection costs to the grid or project development costs; although these costs can be insignificants for small size PV plants, could have an important effect in utility-scale PV; nevertheless Figure 9 will provide a base reference for the further results.

When we deal with the LCOE for PV, a common dismissed element is the cost associated to a possible replacement of inverters; which is reasonable cost, considering a span life between 20-30 years; going beyond it could also been arguable to include residual values of the PV cells, this is an income for the recycling; could also be included dismantling cost, or the social benefits by producing from a renewable source instead of a pollutant one.

Moreover, forecasting an increase in the PV energy production; work in [16] stands, "*High shares of solar PV can be only achieved if storage solutions overcome the variability and impossibility of production of solar energy at night*"; pointing out the necessity to include the battery systems costs in the LCOE for future projects.

Therefore, LCOE is a methodology in constant updating state and it can be as robust as the study case requires.

3.2 Definition of the LCOE Parameters

The definition of the LCOE parameters in this work is given mainly by the characteristics of the DM 2019 and taking advantage of the available information such as real energy produced by already installed plants.

The LCOE equation proposed for the current work includes all the costs and profit margins of the whole value chain and is presented as follows:

$$LCOE = \frac{CAPEX_{t=0} + \sum_{t=1}^{T} \frac{OPEX_t}{(1 + WACC_{nom})^t} + \frac{Inv}{(1 + WACC_{nom})^{T/2}}}{\sum_{t=1}^{T} \left(\frac{E_{yield} \times (1 - Degr)^t}{(1 + WACC_{real})^t} \right)}$$

Equation 4

Where,

CAPEX: is the capital expenditure invested in the year 0 [€/kWp]

OPEX: are the operation and maintenance expenditure at year t [€/kWp]

Inv: is the cost of the invert replacement [€/kWp]

E_{yield}: is the initial Energy yield at year 0

Degr: is the annual Degradation of the nominal power system

T: is the time horizon

$WACC_{nom}$: is the nominal weighted average cost of capital

$WACC_{real}$: is the real weighted average cost of capital

Equation 4 is a modification from the studies made in [16] and [17] and takes advantages of some characteristics such as the degradation rate; but also has specific features according with the information availability and the own work.

The rates $WACC_{nom}$ and $WACC_{real}$ are related by Equation 5:

$$WACC_{real} = \left[\frac{(1 + WACC_{nom})}{(1 + Infl)}\right] - 1$$

Equation 5

Where,

Infl: is the inflation rate.

As presented in [16], using nominal WACC to discount the expenditures and operating with real WACC the electricity generation, ensures that the net present value for the investment with nominal WACC is zero when valuing the generated electricity for the real LCOE.

With respect to the study cases where to use the LCOE proposed, as was presented in Chapter 2, the two kinds of benefits from DM 2019 depend on the power capacity; to assess the economic scenarios will be take in consideration two theorical plants with nominal power of 250 kWp and 1000 kWp.

This is important because the PV expenditures show a scale economy performance and are not linear with the power installed; therefore, the Equation 4 will be applied for both capacities.

3.2.1 Capital Expenditure - CAPEX and Inverters

CAPEX measured in [€/kWp] varies according to the plant size when there is a considerable difference in capacity due to the decreasing costs of economies of scale, mainly in the connection components and planification activities. For new projects installation, some works as presented in [16] use a Learning Rate (LR) methodology, which involve a constant decrease in costs because the improving in technology. In mentioned work the European average for CAPEX was set in 0,46 €/Wp.

According to the last version of the National Survey Report of PV Power Applications in Italy 2018 [19], plants with capacity over 10 kW have the CAPEX showed in Table 7.

Table 7 Cost Breakdown for PV > 10 kW [19]

Cost Category	Average [€/Wp]	Low [€/Wp]	High [€/Wp]
Hardware			
Module	0,26	0,2	0,33
Inverter	0,06	0,05	0,07
Mounting material Other electronics	0,12	0,11	0,13
Subtotal Hardware	**0,44**	**0,36**	**0,53**
Soft Costs			
Planning and Installation Work	0,04	0,03	0,05
Shipping and travel expenses to customer	0,02	0,01	0,02
Permits and Commissioning	0,03	0,02	0,04
Project Margin	0,16	0,14	0,17
Subtotal Soft Costs	**0,25**	**0,20**	**0,28**
Subtotal (excluding VAT)	**0,69**	**0,56**	**0,81**
Average VAT	10%	10%	10%
Total	**0,76**	**0,62**	**0,89**

Data in Table 7 help as reference to set the CAPEX of the work. Following the methodology in [16] with a CAPEX of 0,46 €/Wp and the costs in the presented table, the value seems a bit optimistic, this is expected due the learning process assumed their study.

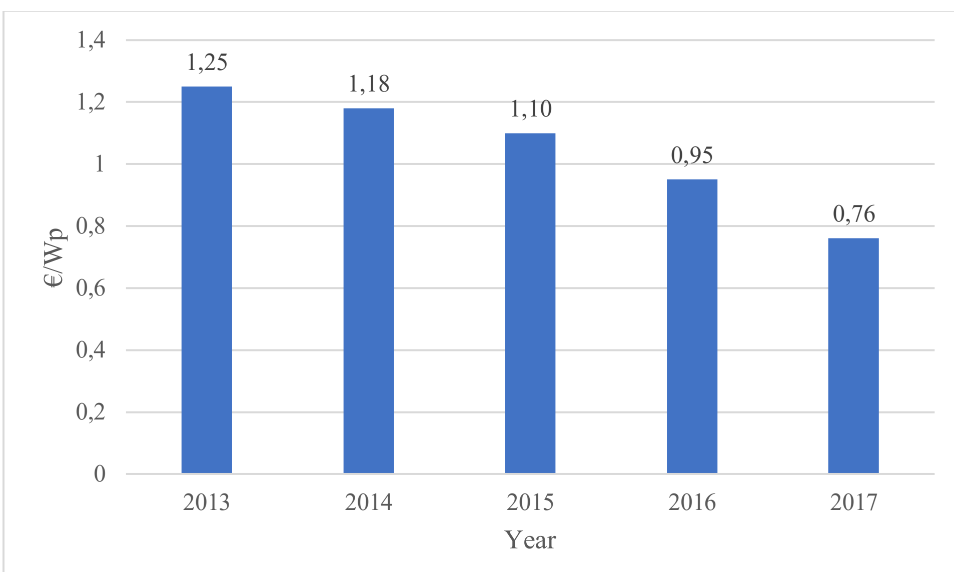

Figure 10. Average CAPEX for PV plants in Italy [20]

In Figure 10 is showed the CAPEX evolution in PV plants in Italy, reported by the Ministry of Development [20].

The average cost of 0,76 €/Wp in 2017, concords in trending with the National Survey Report of PV Power Applications in Italy 2018.

According with the methodology in [16] and the costs in [19]; a coherent CAPEX for 2019-2020 should have a lower value than 0,76 €/Wp and be as much optimistic as desired to reach a cost equal to 0,46 €/Wp; even though, the main goal of this work is to assess the economic performance according to the current regulation in Italy (DM 2019); for that reason is preferred to be a bit conservative with the selected values in order to guarantee "bad scenarios".

Said that, the cost range in years 2018-2019 is set into the minimum and the average costs from Table 7. Additionally, Equation 4 assumes a replacement of the inverters discounted with the $WACC_{nom}$, which is also found in Table 7.

Same range of CAPEX applies for both scenarios plants; this is because the size difference is not big enough to influence the relation €/Wp in the hardware and soft costs; this can be appreciated in the classification by capacity in the turnkey PV systems prices showed in Table 8 Turnkey PV System Prices Table 8.

Table 8 Turnkey PV System Prices [19]

Category/Size	**Current Price [€/kWp]**
Residential BAPV 5-10 kW	1,20 - 1,60
Small Commercial BAPV 10 - 100 kW	1,15 - 1,25
Large Commercial BAPV 100 - 250 kW	1,10 - 1,15
Industrial BAPV 250 kW - 1000 kW	0,80 - 1,00
Small centralized PV 1 - 20 MW	0,70 - 0,80
Large centralized PV > 20 MW	0,55 - 0,70

Therefore, the extreme range costs will be assigned to both power capacity scenarios, arguing that 250 kW is a bit more expensive by €/Wp than the 1000 kW; same logic applies for the inverter costs.

$CAPEX_{250\ kW}$ = 0,76 €/Wp

$CAPEX_{1000\ kW}$ = 0,62 €/Wp

$Inv_{1000\ kW}$ = 0,05 €/Wp

$Inv_{250\ kW}$ = 0,06 €/Wp

3.2.2 Operational Expenditure - OPEX

OPEX for PV plants has presented in the last years the same tendency performance as the CAPEX does, although has not being so studied or included in most of the global reports, mainly because the low contribution percentage to the total costs, the true is that OPEX have had a constant decrease in real money invested through the years and have shifted the business model of the PV owners.

Some models as presented in [17] consider a 5% O&M average from the CAPEX; a value considerable high in comparison with the 1% presented in [16]; nowadays the trend in CAPEX is to shift from a scheduled/preventive maintenance towards a predictive maintenance, reducing even more the associated costs.

Once upon ago, when O&M prices were extremely high, Europe reported average costs around 35 €/kWp/a in 2011 for a full service which included monitoring, periodic or preventing maintenance, corrective maintenance, module cleaning and grass cutting; a tendency in continuous decline reaching 21.7 €/kWp/a in 2013, 19.4 €/kWp/a in 2014; 13 €/kWp/a in 2016 and 9.35 €/kWp/a in 2017 [16].

Under this panorama a first estimation of 1,5% of the O&M will end up in costs between 10,5 €/kWp/a – 8,5€/kWp/a for the both scenario plants; a result which seem to be rational according with the tendency just presented and taking in consideration the high CAPEX selected before. Besides the typical O&M, other components counting in OPEX could be the land lease, insurance, grid fees, balancing, asset management, and various taxes. Being again pessimistic it will be set the additional OPEX components as double of O&M resulting a final rate of 3% of the COPEX.

$OPEX_{250\ kW}$ = 0,021 €/Wp

$OPEX_{1000\ kW}$ = 0,017 €/Wp

3.2.3 Weighted Average Cost of Capital - WACC

WACC reflects the way in which the project is financed, its definition could be crucial in the viability and return of the projects; in this work were defined two rates: $WACC_{nom}$ and $WACC_{real}$; the first one depending of the debt interest and the second one influenced by the inflation.

$WACC_{nom}$ gives the equity-debt rate balance, according to the next equation:

$$WACC_{nom} = \frac{(D \times k_D) + (E \times k_E)}{D + E}$$

Equation 6

Where,

D: is the debt financing

k_D: is the interest rate in debt financing

E: is the equity financing

k_E:is the interest in equity financing

The D/E ratio used in this works is 70/30; this proportion is one of the most common used in PV economic studies as presented in the European average [16] and also [21] in an economic sensitive valuation.

The debt interest rate is taken from Table 9, according to the National Survey Report of PV Power Applications in Italy 2018 and the equity interest is defined taking as a reference that k_E yields 2-2,5 times more than k_D.

Table 9 PV Financing Information in Italy 2018 [19]

Market Segments	**Loan Rate [%]**
Residential Installations	3,5 - 5,0
Commercial Installations	2,5 - 3,5
Industrial and ground-mounted installations	1,6 - 2,0

Therefore, the work values are:

D: 70%

k_D: 3%

E: 30%

k_E: 8%

Resulting in a $WACC_{nom}$ = 4,5%

Forecast inflation can be difficult and is out of the context of this work, even though, in general terms, Italy has presented a steady inflation rate in the last years, for that reason will be take the average of these years as the work inflation rate.

Historic Italian inflation corresponds to the inflation rate based upon the consumer price index (CPI) comparing the December CPI to the December CPI of the year before. According to date reported in [22] the inflation selected for the work as the average of the last 10 years is 1,3%.

With rate of 1,3% now is possible to set the $WACC_{real}$ = 3,2%

3.3.3 Energy and Degradation

This work will take advantage of the real PV plants installed by *IMAM Ambiente,* a company specialized in renewable energy with active plants in Italy and abroad [23].

Through the GSE Performance Platform it is possible to gather the energy production of the IMAM PV plants along the years. There are two relevant plants coinciding in characteristics with the plant scenario of 1000 kWp: *PV Le Forche* and *PV Spietri.*

Table 10 Relevant IMAM PV Plants [23].

Characteristics	**PV**	
	Le Forche	**Spietri**
Location	Apulia	Apulia
Surface	30565	30528
Power	993,60 kWp	993,60 kWp
Inverters	3 inverters	3 inverters
N° Panels	4320	4320

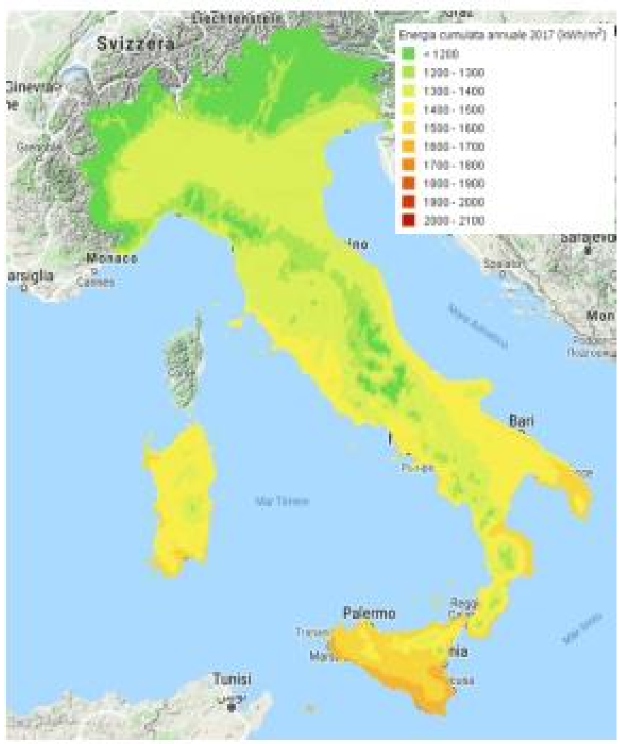

Figure 11. Cumulated Solar Radiation in Italy 2018 [13]

As is showed in Table 10, both PV plants are in the Apulia region corresponding with one of the best solar irradiations into the country (Figure 11). The capacity corresponds to a power very close to the scenario of the 1000 kWp; hence, this will be the reference to estimate the initial energy.

The total energy produced by each plant is showed in Table 11. Energy Produced in the First Effective Year of the Plant, the energy values were collected from the statistics of *Le Forche* and *Spietri* reported in the GSE Platform, for further information it's possible to check the Appendix 1.

Table 11. Energy Produced in the First Effective Year of the Plant

Real Energy Produced		
Month	**Spietri [MWh]**	**Le Forche [MWh]**
Jan	95	85
Feb	85	82
Mar	148	81
Apr	140	157
May	171	135
Jun	182	159
Jul	168	182
Aug	184	172
Sep	140	183
Oct	96	148
Nov	63	120
Dec	76	76
Total	**1548**	**1580**

Appendix 1

In Table 11 the effective energy means the energy corresponding to the calendar year January-December, this because during the first months plants' installation no energy was recorded (Appendix 1); therefore in order to organize the information and make it coherent with the methodology; the month of January selected, corresponds to the first January registered along the operational years of the plants.

Thanks to the real energy produced is possible now to set the energy yield, being the relation kWh/kWp/year, as was explained in the LCOE drivers.

Considering both plants it's obtained a yield of 1559 kWh/kWp/year for *Spietri* and 1591 kWh/kWp/year for *Le Forche.*

Therefore, the yield selected is the average of the mentioned results; for the 250 kWp applies the same value, because this yield is determined by the solar radiation and the panels efficiency, regardless the capacity size.

$E_{yield\ 250kW}$ = 1575 kWh/kWp/year

$E_{yield\ 1000kW}$ = 1575 kWh/kWp/year

Notice that the energy yield does not have a final unit, is more like a rate and a certain way the units kWh/kWp/year doesn't make sense, this is because the yield is not properly a physical quantity but rather a convention among the fabricators, which has been adopted by the PV project developers.

Also is important notice that the Energy yield is written as kWh/kWp/year just because is the international standard presentation form, but could also be presented as Wh/Wp/year and make it more coherent with the units of CAPEX, OPEX, etc; but as it performs like a rate, does not make any difference when is used for the LCOE computations.

Another important comment is that the two theorical plants supposed to be located at same region, which is a reasonable assumption due to the weather conditions and the fact that already IMAM installed plants there. The energy yield calculated trough the real produced energy gives more confidence to this work, instead of assuming average values from other technical studies or radiation simulation software, real date is run.

Finally, the value of 1575 kWh/kWp/year is a good quality yield which was expected because of the solar radiation rates of the region and is higher than the yield used in other studies in Europe, where the averages go around 1200 - 1450 kWh/kWp/year.

With respect to the degradation of the panels, some recent works as in [17] take a degradation rate of 0,7%; others as the thesis presented in [21] assumes a degradation rate of 0,6% yearly counted; other authors claim that the real degradation is between 0,2% and 0,5% [16]. Considering that the degradation is more a question of the product quality could be argued that the capacity does not influence the rate. Some LCOE models don't include the degradation and accept a constant energy for sake of simplicity; just the fact to include a degradation rate gives a more realistic approach to this work and to guarantee once again pessimistic scenarios the rate used will be of 0,7%.

The life span is set in 30 years according to the PV life system recommendations of the International Energy Agency.

In Table 12 are summarized the final parameters to compute the LCOE for both scenarios of PV plants.

Table 12 Final Parameters for the LCOE

Parameters	**PV Plant**		**Unit**
	250 kWp	**1000 kWp**	
CAPEX	0,76	0,62	€/Wp
Inverters	0,06	0,05	€/Wp
OPEX	0,021	0,017	€/Wp
WACC nom	4,50%	4,50%	%
Inflation	1,30%	1,30%	%
WACC real	3,20%	3,20%	%
Energy yield	1575	1575	kWh/kWp/year
Degradation Rate	0,7%	0,7%	%
Life Span	30	30	year

Mentioned scenarios are the Base Cases by capacity to study and are useful as a reference for the DM incentives application, even though, it will be also considerate a sensitive analysis, variating some parameters in the LCOE.

3.3 DM 2019 Incentives

Thus far, it has been defined the methodology for computing the costs by energy unit from the PV plants, next step is to specify the type of the incentives and the fee values contemplated in the DM 2019.

From Table 5 in chapter 2, are already known the groups of which PV plants belong and the two typology definitions for an eventual premium payment, Table 5 also provides the useful life and the Reference Tariff according to the installed power; now is the time to go in more detail towards the revenues for trading the energy according to the specifications in the DM 2019.

3.3.1 Remuneration methodology of the DM 2019

DM 2019 states that remuneration for PV plants is guaranteed for the net energy produced injected to the grid, which correspond to the minor value between the net production and the effective energy injected to the grid; providing the following definition:

- **Net Production**: Gross production less the energy absorbed by the auxiliary services of the central, losses in the principal transformer, and losses in the conductor until the delivery point to the grid [15].
- **Effective Energy Injected to the Grid:** Electrical energy produced and injected from the plant in the connection point to the grid, this value is determined by the Grid Distribution Administrator [15].

Now is the time to know how is going to be remunerated the energy mentioned before.

In the following are presented the definitions of the two kind of incentives [15]:

1. *Tariffa Omnicomprensiva - To* (Comprehensive Tariff)
2. *Incentivo – I* (Incentive)

PV plants with capacity below or equal to 250 kW may apply to both possibilities, whilst plants with capacity over 250 kW can access exclusively to Incentive. The numerical definition of the fee is presented as follows:

$$T_o = T_{spet} \quad ; \quad \mathrm{I} = T_{spet} - P_z$$

Equation 7

Where,

- T_{spet}: *Tariffa Spettante* (Relative Tariff).
- P_z: *Prezzo Zonale* (Zone Price), is the hourly price in the zone in which the energy is injected into the grid.

T_{spet} depends on the Offered Tariff and eventual penalties, to follow is explained the mechanism in the DM 2019.

- *Tariffa di Riferimento* - T_{rif} (Reference Tariff): is determined as a function of the source and power capacity of the plant.
- *Tariffa Offerta* - T_{off} (Offered Tariff): applied to the Reference Tariff.

$$T_{off} = T_{rif} \times (1 - \%Rid_{off})$$

Equation 8

- *Tariffa Spettante* - T_{spet} (Relative Tariff): is fixed along the entire period of right to access of one of the incentives.

$$T_{spet} = T_{rif} \times (1 - \%Rid_{off}) \times (1 - \sum \% Rid_n)$$

Equation 9

Where,

- $\%Rid_{off}$ is the *Riduzione Percentuale Offerta* (Percentage Reduction Offered) in the range of 0,01-30%.
- $\%Rid_n$ are the *Riduzioni Applicabili* (Applied Reductions) according to different specifications, as follows:

I. $\%Rid_{15+12mesi}$: Reduction of 1% per year for plants entered in operations after 15 months from the graded list [15].

- Entered in operation between 15° and 27° months; reduction of 1%.
- Entered in operation between 27° and 39° months; reduction of 2%.
- Entered in operation between 39° and 51° months; reduction of 3%.
- Entered in operation between 51° and 56° months; reduction of 4%.

II. $\%Rid_{RitardoEsercizio}$: Reduction for delay in entered operations according to the next table:

Table 13Maximum Allowed Time to Enter in Operation [15].

PV Source	Time to Enter in Operation		Maximum Delay
	Not Public Administration	In Public Administration	
Group A	19 months	25 months	6 months
Group A-2	24 months	30 months	6 months

The reduction worth 0,5% for each delay month.

III. $\%Rid_{ContoCapitale}$: Reduction in case of recognition of capital contribution; the reduction is applied in a linear way from 0 (no capital contribution) to 26% referred to a capital contribution equals to 40% [15].

IV. $\%Rid_{ComponenteRegenerati}$: Reduction of 20% for the selected plants using components regenerated [15].

V. $\%Rid_{DM2019}$: Reduction of 5% for plants that resulted beneficiaries from a graduation list but have not started the operation; applied also for those who reject the benefits after 6 months of the said graduation list [15].

VI. $\%Rid_{Transferimeto\ terzi}$: Reduction of 50% of the Offered Tariff for the project that transfer the plants to a third party [15].

VII. $\%Rid_{DM2016}$: Reduction of 15% for the plants that resulted beneficiaries in the DM 2016 graduation list but have not started the operation; applied also for those who reject the benefits after 6 months of the said graduation list. The DM 2016 did not include incentives for PV projects [15].

VIII. $\%Rid_{DM2012}$: Reduction of 6% for the plants that resulted beneficiaries in the DM 2012 graduation list but have not started the operation; applied also for those who reject the benefits after 6 months of the said graduation list [15].

In the Table 14 are summarized all the reductions with the relevant information and whether applicable for PV projects.

Table 14. Reductions Percentages for PV plants [15]

Name	Reduction Percentage	Applied to PV plants
$\%Rid_{15+12mesi}$	1% - 4%	No
$\%Rid_{RitardoEsercizio}$	0,5% per month	Yes
$\%Rid_{ContoCapitale}$	0-26%	No
$\%Rid_{ComponenteRegenerati}$	20%	No
$\%Rid_{DM2019}$	5%	Yes
$\%Rid_{Transferimeto\ terzi}$	50% from Offered Tariff	Yes
$\%Rid_{DM2016}$	15%	No
$\%Rid_{DM2012}$	6%	No

With the whole set of reductions is possible now to interpret the Equations of T_{off} and T_{spet}; in Equation 8 the Offered Tariff depends exclusively of the investor intentions; it means the revenues he expect to receive for the project.

In the other hand, Equation 9 shows dependency of different kind of reductions, in this case the Relative Tariff relays in the planification and execution of the project from the investor side. Both equations can result with the same tariff only if the PV project has not setbacks, it means if the investor is not penalized for any reason during the installation period.

3.3.2 Study Cases for the 250 kW and 1000 kW PV plants

Two theorical plants by capacity 250 kW and 1000 kW were selected in order to have a diversity in the LCOE results but also to assess the influence in the payment methodology.

From the incentives point of view the best outcomes result from a low offered reduction and no penalties; even though the main scope of this work is to assess the influence of the DM 2019 methodology, for that reason are proposed the following Study Cases:

- Case 1: Reduction Offered between 0,01% – 10% and no penalties
- Case 2: Reduction Offered between 0,01% – 10% and delay in the operation entrance among the first 6 months ($\%Rid_{RitardoEsercizio}$)
- Case 3: Reduction Offered between 0,01% – 10% and delay in the operation entrance after 6 months ($\%Rid_{RitardoEsercizio}$) and ($\%Rid_{DM2019}$)

- Case 4: Reduction Offered between 10% – 30% and delay in the operation entrance among the first 6 months ($\%Rid_{RitardoEsercizio}$)
- Case 5: Reduction Offered between 10% – 30% and delay in the operation entrance after 6 months ($\%Rid_{RitardoEsercizio}$) and ($\%Rid_{DM2019}$)
- Case 6: Property transference ($\%Rid_{Transferimeto\ terzi}$)

As was showed before, it is possible to divide the cases according to the penalties by delay in operation entrance, by capital contribution and by property transference; is also expected that said type of penalties do not apply simultaneously; because this is relevant information known since the planification process, it means that an investor already knows in advance the project features and remuneration that expects to receive.

For example an investor that already knows that his project has a 40% of capital contribution expects to have a 26% of penalties for the Relative Tariff, if he also registers the plant with the maximum reduction of 30% from offered tariff and then, in advance, plans to transfer the project towards a third party reducing an additional 50% to the mentioned offered tariff; is clearly risking himself to do a bad investment. Mentioned scenario could actually happen for different reasons, a PV owner could have to be enforce to transfer the PV property, but clearly this was not the first project objective; so here, there will not be deal with extreme pessimistic scenarios from the remuneration point of view, the maximum objective conclusion for that projects would be that they are not profitable, following the common sense.

In the other hand the work will be focused to the maximum acceptable penalties by project and the relation with the offered tariff.

The mentioned cases applied for both plants, in the case of the 1000 kW plant, besides the Relative Tariff according to Equation 7 it is necessary to discount the Zone Price.

The zone price is the monthly average price per hour in the spot energy market and is set according to the region of the country. Italy has 6 zone price regions as is showed in the Table 15, and for the current work the interest region is Sud.

Therefore, to assess the 1000 kW plant is proposed to collect the zone prices of the Sud region in the last 10 years and to measure a sort of historical probability where the Incentive reaches negative values taking the reference of the Relative Tariff in Equation 7.

Table 15 Regions for the Zone Price [15]

Zone Name	Acronym	Regions
Centro Nord	CNOR	Tuscany, Marche, Umbria
Centro Sud	CSUR	Lazio, Abruzzo, Campania
Nord	NORD	Aosta Valley, Piedmont, Liguria, Lombardy, Trentino, Veneto, Friuli Venezia Giulia, Emilia Romagna
Sardegna	SARD	Sardinia
Sicilia	SICI	Sicily
Sud	SUD	Molise, Apulia, Basilicata, Calabria

Furthermore, for an economic assessment, the prices paid to the PV plants depends on the day and hour when the energy is injected, in Italy there are three bands (*Fascia*) with a well stablished schedule, depending of the load profile.

Table 16. Hours per Band to define the Zone Prices [5]

Hour	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Monday - Friday	**F3**							**F2**	**F1**											**F2**				**F3**
Saturday	**F3**							**F2**																**F3**
Sundays/Holidays	**F3**																							

Table 16 is useful for being more accurate at time of revenues computation and to understand the possible zone prices to be discounted for the 1000 kWp PV plant.

Figure 12 shows the last 10 years average energy price of the *Mercato del Giorno Prima* (Day-Ahead Market - DAM) for the Sud region in correspondence with the three Bands (F1, F2, F3). Mentioned price is the monthly price to be discounted from the Incentive in Equation 5.

Although the average price is useful to simplify possible calculations, in order to go in a deeper analysis of the possible revenues for the 100 kWp PV plant, is also necessary to know the extreme prices paid during said years.

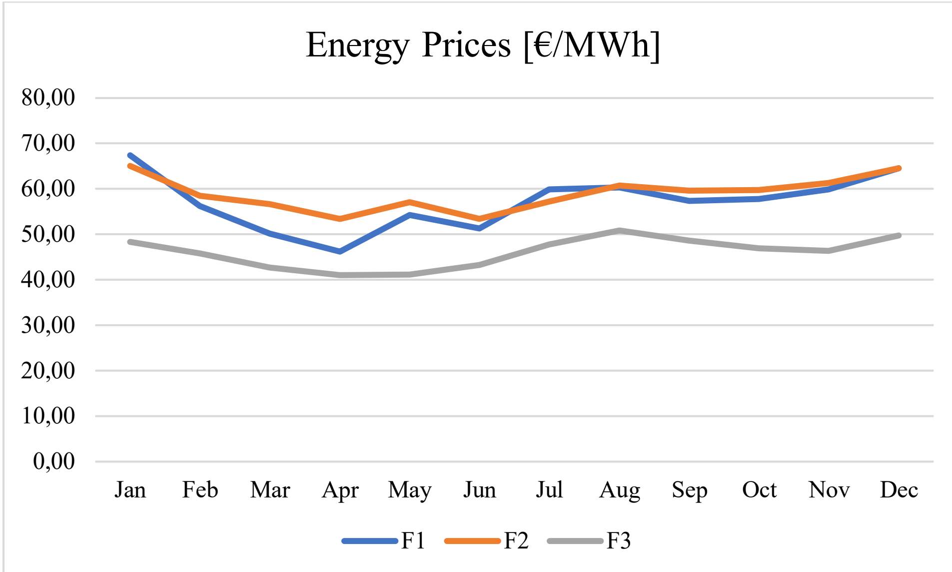

Figure 12. Sud Region Monthly Energy Price 2009 – 2019

Furthermore, for the 250 kWp plant, the zone price plays also an important role after the 20 years of the Tariff guaranteed by the DM 2019, because the project's life span is 30 years, this is one third of the time without grants.

In the work are presented the average prices summed up in the Figure 12; when results be evaluated, additional prices from the data collected are going to be used, the whole set of prices for the Sud region of Italy are listed in the Appendix 2.

4. RESULTS

4.1 LCOE Results

Applying Equation 4 with the parameter from Table 12 to the plants of 250 kWp and 1000 kWp are obtained the following LCOE values:

Table 17. LCOE results for the PV base cases plants

PV Plant	LCOE [€/MWh]
250 kWp	41,24
1000 kWp	33,58

Values presented in Table 17 must be interpreted as the cost for producing 1 MWh of energy along 30 years. Said cost make totally sense with the tendency work showed in [12] and represented in Figure 9.

These costs will be the base values for further analysis, but first a sensitivity analysis is going to be presented, this mainly to have a broader understanding in the degree of influence of the parameters into the LCOE methodology. The first variations are made for the CAPEX and energy yield drivers.

Appendix 3

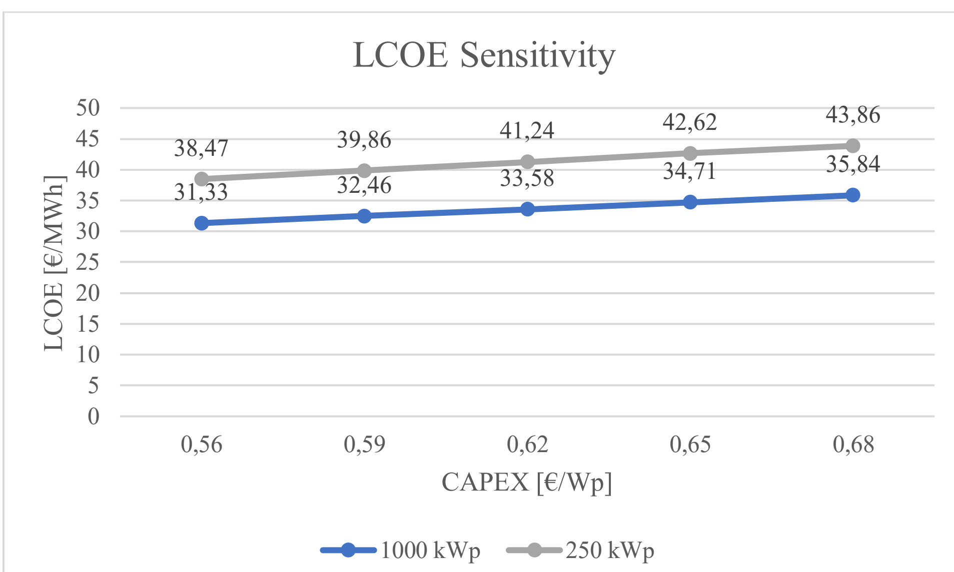

Figure 13. Influence of the CAPEX variation in the LCOE

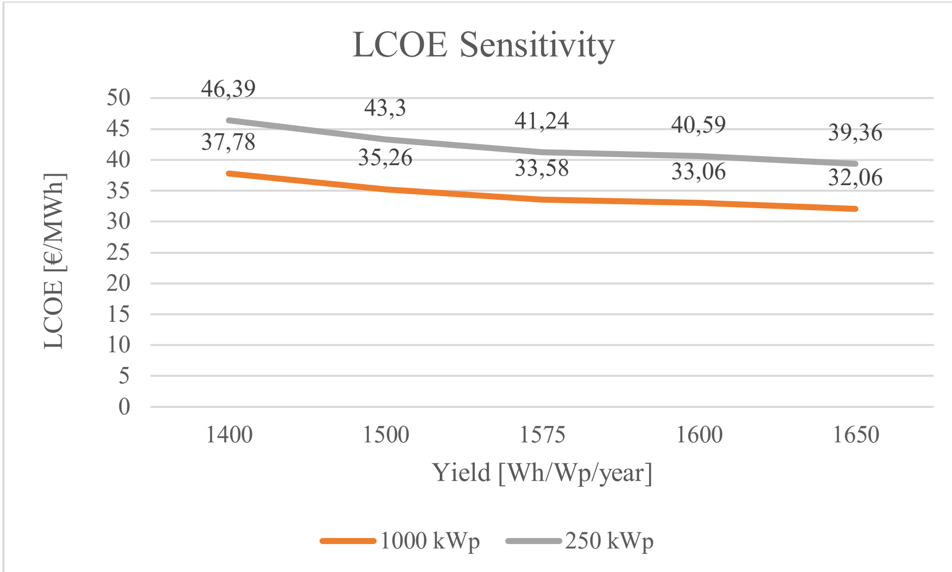

Figure 14. Influence of the Energy Yield variation in the LCOE

The Figure 13 shows a maximum ±10% of CAPEX values; according with the calculations were found that there's a linear variation of 3,34% in the LCOE for each 5% variation in the CAPEX. For the energy yield there's a higher degree of influence, because a 5% variation in the LCOE is reached by a slightly inferior variation in the yield equal to 4,76%; the graphic representation is showed in Figure 14, tables with the calculations to obtain the presented figures and the rest ones in Chapter 4 appear in the Appendix 3.

4.2 Study Cases Results

For covering the six cases defined before, a set of Relative Tariffs is going to be presented for each PV; the idea is to have a reference income for the futures cash flows to do the economical assessment. The minimum and the maximum tariffs are presented in Figure 15; is useful at this point to recall that the Relative Tariffs are the result of the discount offered by the plant and the penalties associated to the cases. In the figure is also show the LCOE for each plant with the intention of giving a visual help to understand the difference in the possible incomes and expenses; basically can make inferred from the figure that the case 6 is undesirable. Although a detail economic evaluation has not be carried out yet; the intuition prevents from a careful situation where the expenses are almost equal to the possible income.

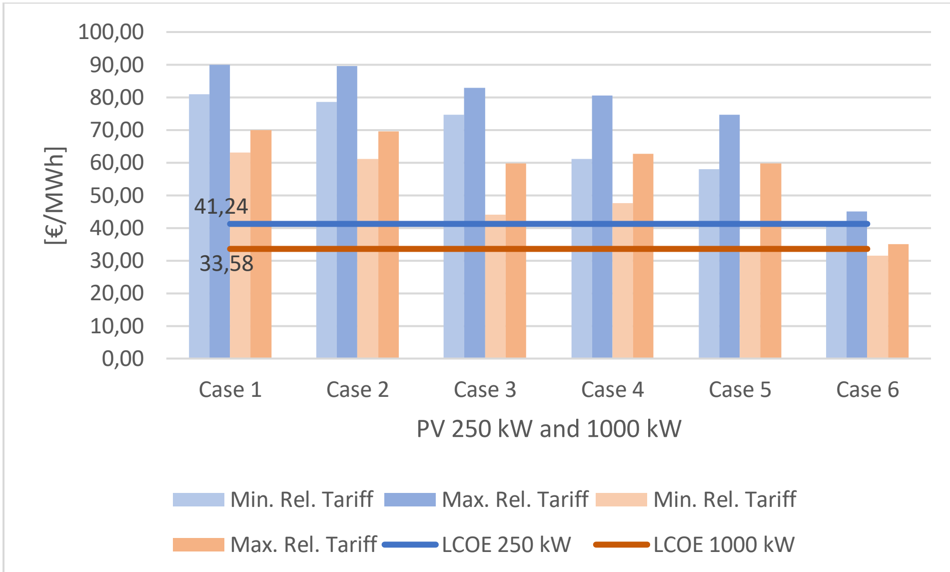

Figure 15. Relative Tariffs for the two PV plants

Figure 15 gives directly the value of the income for the 250 kW, this means that the Relative Tariff is the price that the plant is going to receive; in the other hand according with Equation 7, the Relative Tariff for the 1000 kW is a function of the zone price. Due the fact that electrical markets are known for their high uncertainty and volatility, a different approach is proposal:

- The yearly profit of the 1000 kW is given by:

$$\pi_{1000kW} = (E_{unit} * I) - Costs = E_{unit} * (T_{spet} - P_z) - LCOE_{1000\ kW}$$

Equation 10

- The plant could offer its energy to the spot market directly without any agreement of incentive and receive P_z for each MWh injected to the grid.
- So, the plant is subjected to two constrains:

$$T_{spet} \geq 2P_z; \qquad P_z \geq LCOE_{1000\ kW}$$

- Otherwise the plant prefers to sell the energy to the spot market or any Power Purchase Agreement (PPA) with higher value than the LCOE.

- According with the historical data of spot energy market prices in the last ten years, the second constraint is accomplished most of the months for the three bands.
- In the other hand the first constraint will be also depending of the Offered Tariff and penalties.
- Therefore, at this point it's convenient to restrict the number of cases where there's an opportunity that the first constraint could be reached; based specifically in the set of Relative Tariff showed in the Figure 15.
- After the inspection, are immediately dismissed the Cases 3,4,5 and 6; due the low values represented against the average of the three bands in Figure 12.
- If we take in account the average prices, Cases 1 and 2 neither fulfil with the constraint; but just to have a deeper analysis, the complete set of prices showed in Appendix 2 was evaluated trying to tabulate the number of times when the constraint 1 was accomplished. The logic tables developed are showed in the Appendix 2, and the results are the following:

Table 18. Percentage accomplished for the Constraint 1

Compliance of Constraint 1 for the 1000 kW PV plant				
Band	**Case 1 min**	**Case 1 max**	**Case 2 min**	**Case 2 max**
F1	3,03%	6,06%	3,03%	6,06%
F2	0,00%	3,03%	0,00%	1,52%
F3	5,30%	12,88%	5,30%	12,88%

Appendix 2

Table 18 contains a powerful information about the economic assessment for the 1000 kW plant and beyond than that, the addressing of the DM 2019. In Table 18 the percentages corresponds to the months in the last ten years in which the constraint 1 was accomplished in the three bands; it means than according with the monthly zone price average, the hypothetical 1000 kW plant could be profitable only few times along the years. This is totally correlated with the Equation 7, where the higher the zone prices the lower the incentive the plant can appropriate.

It's important to mention two remarkable aspects about the previous result; the first is that even the evaluation was made with zone prices of the past (in the last 10 years), there's no guarantee that the prices are going to have an important decrease in future years, rather, it will expected a rise due to inflation and external factors, enter in this estimation is out of the scope of this thesis, but the statement should be that as is consigned in the academic works, the electrical markets are one of the most volatile markets, therefore with the available data the results found show that under those real past prices, a 1000 kW plant entering in a DM incentive agreement would not make profit, considering the monthly prices and the expenses represented in the LCOE.

Additionally, the best percentage of 12,9% is reached when the case 1 and 2 have the higher Offered Tariffs and low penalties; this means, even under optimistic scenarios from the offer side, the economic outcome is significantly poor.

At this point, the highlighted aspect is that contrary to initial insights about the DM 2019; the grants could not be beneficial to any kind of PV plant; the size, the efficiency in the implementation, and the technical aspects play determinant roles in the viability of the projects. In particular, for the 1000 kW theorical plant, the evidence shows that is not a good business to enter in the DM 2019 auction because it would meant to incur in risks out of its control, as the zone price which influences directly the potential profit.

4.3 Economic Assessment of the 250 kW Project

Once that was defined that the 1000 kW plant is better off without selling the energy trough the Incentive of the DM 2019, the works is going to be focused on the economic results for the 250 kW, evaluating the 6 cases mentioned before.

The method selected is the Net Present Value (NPV) because offers flexibility in the computation of the cash flows. To make a more realistic approach, the traditional NPV is adjusted based on the project characteristics.

$$NPV = \sum_{t=1}^{t=20} \frac{(E_t * To_t) - OPEX_t - Inv_{15}}{(1 + WACC)^t} + \sum_{t=21}^{t=30} \frac{(E_t * Pz_t(t)) - OPEX_t}{(1 + WACC)^t} - CAPEX_0$$

Equation 11

Where;

E_t: is the energy produced in the year t, the initial energy produced is just the yield multiply by the peak power; (1575 kWh/kWp/year)*(250 kWp) = 393,75 MWh produced at t=1.

To_t: is the grant income the plant is going to perceive according to the relative tariff as it was showed in Equation 7.

$OPEX_t$: are the operational expenses computed before for the LCOE.

Inv_{15}: is the cost of the replacement of the inverters, which applies only at year 15.

$Pz_t(t)$: is the zone price, from which the plant can obtain income after the year 20.

$CAPEX_0$: is the initial investment, used also in the LCOE calculation.

In Equation 11, the Pz is dependent of the time because is the price taken from the market, then is a random variable that for sake of simplicity is going to be assumed according to the Figure 12 (historical market prices in the three bands), and adjusted according to the inflation. The yearly energy produced is going to be altered according to the degradation rate, in concordance with the LCOE, so it's expected a diminution with the past of the time. The Equation 11 is going to be applied for the 6 cases of study just to present a broader economic perspective.

To select the Pz, is taken advantage of the historical data presented in Appendix 2, in Table 19 is presented a summary of said data in form of average for the three bands. According with Table 16 (Hours of bands of energy), a solar plant could receive prices mainly from F1 and then in minor percentage from F2 and F3; therefore was decided to make a weighted average of the price and get the final result as the price of reference.

Mentioned price is the price at t=0 (year 2020); the income with the Pz starts at year 21, therefore an increase in the value according with the inflation is proposed; this assumption is coherent but in fact impossible to prove; mainly because as was mentioned in the previous subchapter, the electrical market is one the most volatile markets, besides, according to Figure 12, in the last ten years the average prices seem to be contained in a relative steady fringe with no considerable rises or drops.

Table 19 Average Historical Market Prices

Year	F1	F2	F3
2009-2019	**[€/MWh]**	**[€/MWh]**	**[€/MWh]**
Jan	67,41	65,06	48,29
Feb	56,25	58,52	45,76
Mar	50,22	56,66	42,78
Apr	46,21	53,39	41,03
May	54,33	57,12	41,16
Jun	51,32	53,41	43,24
Jul	59,84	57,17	47,76
Aug	60,30	60,80	50,86
Sep	57,35	59,56	48,61
Oct	57,85	59,71	46,96
Nov	59,97	61,25	46,32
Dec	64,54	64,53	49,75
Average	**57,13**	**58,93**	**46,04**
Weighted Average Price at t=0			**55,81**

In the other hand forecast the prices 30 years ahead, intuitive suggest to consider higher values than the ones in the t=0; for that reason the weighted average Pz from Table 19 is adjusted with the yearly inflation of 1,3% as was done in the LCOE calculate. Now, known the way to obtain the income from year 21 until year 30, the Equation 11 is run to obtain the NPV for the six cases considered.

The results are presented in the Figure 16, where it is possible to observe that most of the cases have positive NPV; the values in the cases 1 and 2 are kind of expected because are optimistic scenarios with high Offered Tariffs and few percentages of penalties; the result of the case 6 is unexpected because corresponds to the case with proper transference which is extremely penalized with a 50% of reduction from the Offered Tariff as was showed in Table 14. In the other hand the results for the cases 3,4 and 5 were not totally obvious (because of the market price since year 21) but are in coherence with Figure 15.

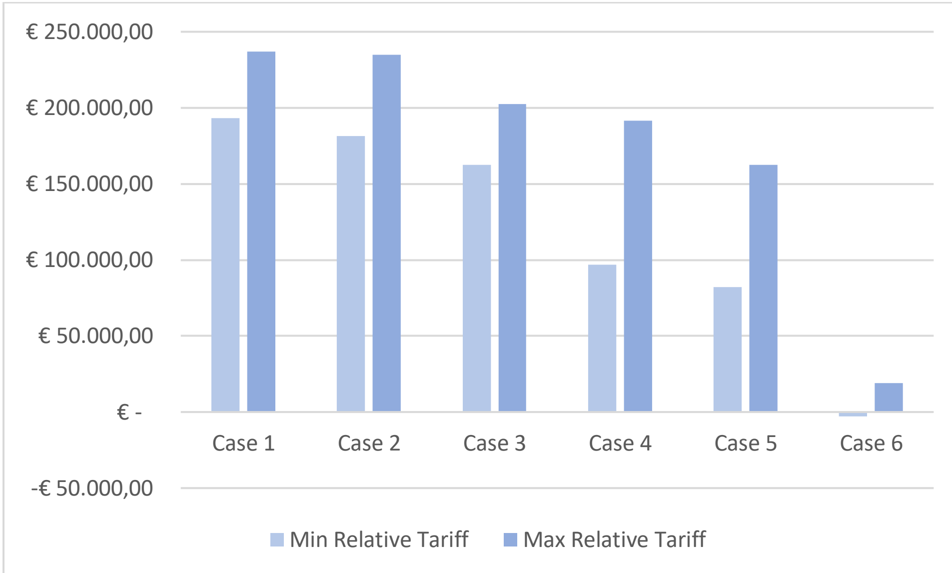

Figure 16. NPV for the 250 kW project

Considering that the CAPEX for the 250 kW plant is €190.000, the high Relative Tariffs could offer more than a 100% of return from the initial investment, in other words the grants for the plants under 1000 kW are specially advantageous. Juts to point out a final consideration, lets recall the cases 4 and 5:

- Case 4: Reduction Offered between 10% – 30% and delay in the operation entrance among the first 6 months ($\%Rid_{RitardoEsercizio}$)
- Case 5: Reduction Offered between 10% – 30% and delay in the operation entrance after 6 months ($\%Rid_{RitardoEsercizio}$) and ($\%Rid_{DM2019}$)

This means that the plant could offer the maximum reduction of 30% from the reference tariff and still be profitable even under delays in the installation times set by the DM 2019.

If the time scope is reduced to 20 years, it means without including the trade in the energy market, the Relative Tariff that becomes the NPV = 0 is T_{spet}= 54,93 €/MWh.

It's interesting how mentioned price is slightly below from the weighted average price from the energy market, but it matches completely with an intuitive analysis in which does not make any sense to offer a price lower than the one could be get from other source (the energy spot market).

Finally, it is important to point out that according with the lines of the DM 2019, the maximum Offered Tariff reduction is equal to the 30% over Reference Tariff = 90 €/MWh; if at that price are applicated the whole penalties the minimum Relative Tariff (without the property transference) is T_{spet}= 58,05 €/MWh; which is the price of the case 5.

4.4 Further Analysis

The methodology of the LCOE and the remuneration through grants stablished in the DM 2019 was tested in the two theorical plants, and was found that the policies are addressed to benefit the projects with capacity under 1000 kW; also was taken in consideration a coherent estimation of the market prices in order to match the span life with the economic assessment time.

In this subchapter are going to be presented topics related with the study but that are out of the scope of the methodology.

1. For the 250 kW plant the NPV results showed that basically in all the cases the project could be profitable. The cases were organized according the application of the penalties reductions without the redundant discounts of the property transfer ($\%Rid_{Transferimeto\ terzi}$), because just with this penalty the projects would struggle to be profitable. In the assessment presented in Figure 16, the NPV is for 30 years including 10 years of energy trade in the spot market and that influences the rise in the outcome. If it’s considered only 20 years of grants (the DM 2019 time) the NPV for a plant becomes negative, even with the higher Relative Tariff after the property transfer which is 45 €/MWh. As was mentioned in the previous subchapter, the other possible Relative Tariffs result in a positive NPV for a useful life of 20 years.

2. For the case of the 1000 kW plant, the formulation of the policy itself in the DM 2019 does not provide a satisfactory incentive due to the opposite effect of the market price. According to the analysis presented, also a plant with higher size would be facing a decision between to enter in the auction or to trade externally the energy; taking in consideration that the LCOE is expected to go down as the size increases, the NPV could

turn it out positive, but still not be the optimal decision as the first constraint presented would still be remained. Basically, a plant granted by the DM 2019 is worst off when the market prices rise.

It's also important to mention than into the category of the plants with equal or larger size of 1000 kW there is a grant with a higher Reference Tariff, equals to 90 €/MWh, that applies to the projects with eternity removal from building roofs; in this case the analysis is different because the process results in an increase in the LCOE, nevertheless it tackles directly the constraint one as should be possible to guarantee an income with higher Relative Tariffs.

Finally, an additional consideration is that the DM 2019 policy is not casual; the fact that low size capacity plants are more benefited from the grants although they have a higher per unit energy cost indicates the intention to focus in a every time more decentralized generation, in concordance with the worldwide status; furthermore forces to the big projects be more efficient. The structure of the DM 2019 confirms the tendency pointed out by some authors where is exposed that the solar plants should compete directly in the energy markets and set their economic activities through PPAs.

5. CONCLUSIONS

- The Feed-In Tariffs in Italy have been a successful implementation for the development of photovoltaic projects. Mentioned success can be easily assessed in terms of capacity. The five *Conto Energia* (FIT) along the years 2005 – 2012 were responsible for more than the 90% of the current installed capacity.
- The *VI Conto Energia – DM 2019* can be considered an evolution from their predecessors, it includes a broader projects discrimination in terms of size, technical features and tariffs. To set the Tariffs, the DM 2019 takes advantage from the decrease in the PV generation costs directly related to external factors as price components, and internal factors as the evolution of a proper PV market expertise in the energy trading.
- The DM 2019 follows a clear worldwide tendency in which the grants to new PV projects are more restrictive due to the generation costs decline. This was proved specially for the cases study of the 1000 kW project, in which basically the plant could be better off not entering in the grant agreement but trading the energy directly in the sport market or through PPAs.
- In the other hand the DM 2019 could be especially profitable for projects with capacity under 1000 kW, because sets a considerable higher Reference Tariff that the average market price and reward the implementation efficiency of the projects.
- The LCOE is a convenient tool to measure the costs generation among energy projects with different characteristics. In the work, the methodology allowed to evaluate the PV plants through their investment, variable costs and potential energy generation
- The guidelines and the nature itself of a policy influences immensely the feasibility of the projects; in the current work was presented that plants with higher costs generation (250 kW) are more profitable than the ones with lower costs.

6. BIBLIOGRAPHY

[1] Gestore Servizi Energetici, **«Fonti Rennovabili in Italia e in Europa - 2017**,» Gestore Servizi Energetici, Roma, 2019.

[2] M. Ragwitz, A. Held y B. Breitschopf, «**Shaping an effective and efficient European Renewable Energy Market,»** INTELLIGENT ENERGY EUROPE, 2011.

[3] Solar Power Europe, **«Global Market Outlook for Solar Power 2019-2023,»** 2019.

[4] Council of European Energy Regulators , **«Status Review of Renewable Support Schemes in Europe for 2016 and 2017,»** Brussels, 2018.

[5] **Gestore Servizi Energetic**i, «https://www.gse.it/,» 11 november 2019. [En línea]. Available: https://www.gse.it/servizi-per-te/fotovoltaico/conto-energia.

[6] Ministero delle Attivita' Produttive, **«Gazzetta Ufficiale della Repubblica Italiana,»** 28 07 2005. [En línea]. Available: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2005-08-05&atto.codiceRedazionale=05A07837&elenco30Giorni=false. [Último acceso: 05 11 2019].

[7] Ministero dello Sviluppo Economico, **«Gazzetta Ufficiale della Repubblica Italiana,»** 19 03 2007. [En línea]. Available: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2007-02-23&atto.codiceRedazionale=07A01710&elenco30giorni=false. [Último acceso: 06 11 2019].

[8] F. Spertino, J. Ahmad, A. Ciocia y P. Di Leo, **«Techniques and Experimental Results for Performance Analysis of Photovoltaic Modules Installed in Buildings,»** *Energy Procedia,* pp. 944-953, 2017.

[9] M. Trapanese, A. Viola y D. Milone, **«A Power Law Behavior in the Incentivized Italian Photovoltaic Market,»** de *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, Palermo, 2018.

[10] Ministerio dello Sviluppo Economico , **«Gazzetta Ufficiale della Republica Italiana,»** 12 05 2011. [En línea]. Available: https://www.gazzettaufficiale.it/eli/id/2011/05/12/11A06083/sg. [Último acceso: 06 11 2019].

[11] Ministero dello Sviluppo Economico , **«Gazzetta Ufficiale della Repubblica Italiana,»** 05 07 2012. [En línea]. Available: https://www.gazzettaufficiale.it/eli/id/2012/07/10/12A07629/sg. [Último acceso: 06 11 2019].

[12] V. Di Dio, D. Lacascia, F. Massaro y G. Zizzo, **«The evolution of the FIT mechanism in Italy for PV systems: a Critical Analysis,»** de *International Conference on Renewable Energy Research and Applications*, Madrid, 2013.

[13] Gestore Servici Energetici, **«Rapporto Statistico Solare Fotovoltaico 2018,»** GSE, Roma, 2019.

[14] Gestore Servizi Energetici, **«Regolamento Operativo per l'inscrizione ai Registri e alle Aste,»** GSE, 2019.

[15] Gestore Servizi Energetici, **«Regolamento Operativo per l'accesso agli Incentive,»** GSE, 2019.

[16] E. Vartiainen, G. Masson, C. Breyer, D. Moser y E. Medina, **«Impact of weighted average cost of capital, capital expenditure, and other parameters on future**

utility-scale PV levelised cost of electricity,» *Progress in Photovoltaics,* p. 15, 2019.

[17] A. Massi, F. Spertino, V. Lugui, P. Rosato y S. Vergura, «**Diminishing costs of electricity from wind power and photovoltaics,»** de *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, Milan, 2017.

[18] International Energy Agency, **«National Survey Report of PV Power Applications in Italy - 2015,»** *International Energy Agency Photovoltaic Power Systems Programme,* p. 24, 2015 .

[19] International Energy Agency, **«National Survey Report of PV power applications in Italy 2018,»** *International Energy Agency Photovoltaic Power Systems Programme,* p. 24, 2018.

[20] Ministerio dello Sviluppo Economico , **«Statista,»** 2019. [En línea]. Available: https://www.statista.com/statistics/945320/capital-expenditure-capex-of-the-solar-pv-industry-in-italy/. [Último acceso: 11 28 2019].

[21] C. Cannatá, **Analisi di sensibilitá tecnico-economica per impianti fotovoltaici di grande taglia installati a terra**, Turin: Tesis LM Politecnico di Torino , 2019.

[22] **Woldwide Inflation Data**, «inflation.eu,» [En línea]. Available: https://www.inflation.eu/inflation-rates/italy/historic-inflation/cpi-inflation-italy.aspx. [Último acceso: 03 12 2019].

[23] IMAM Ambiente , **«IMAM Ambinte - Impianti Fotovoltaici,»** 15 11 2016. [En línea]. Available: http://www.imamambiente.com/it/impianti-fotovoltaici/?p=2. [Último acceso: 03 12 2019].

APPENDIX

Appendix 1

Figure 17 and Figure 18 are the graphs of real energy registered by the GSE for the Spietri and Le Forche plants in the last ten years, the energy reference corresponds to first effective year January – December of 2012, these values were used to obtain Table 11.

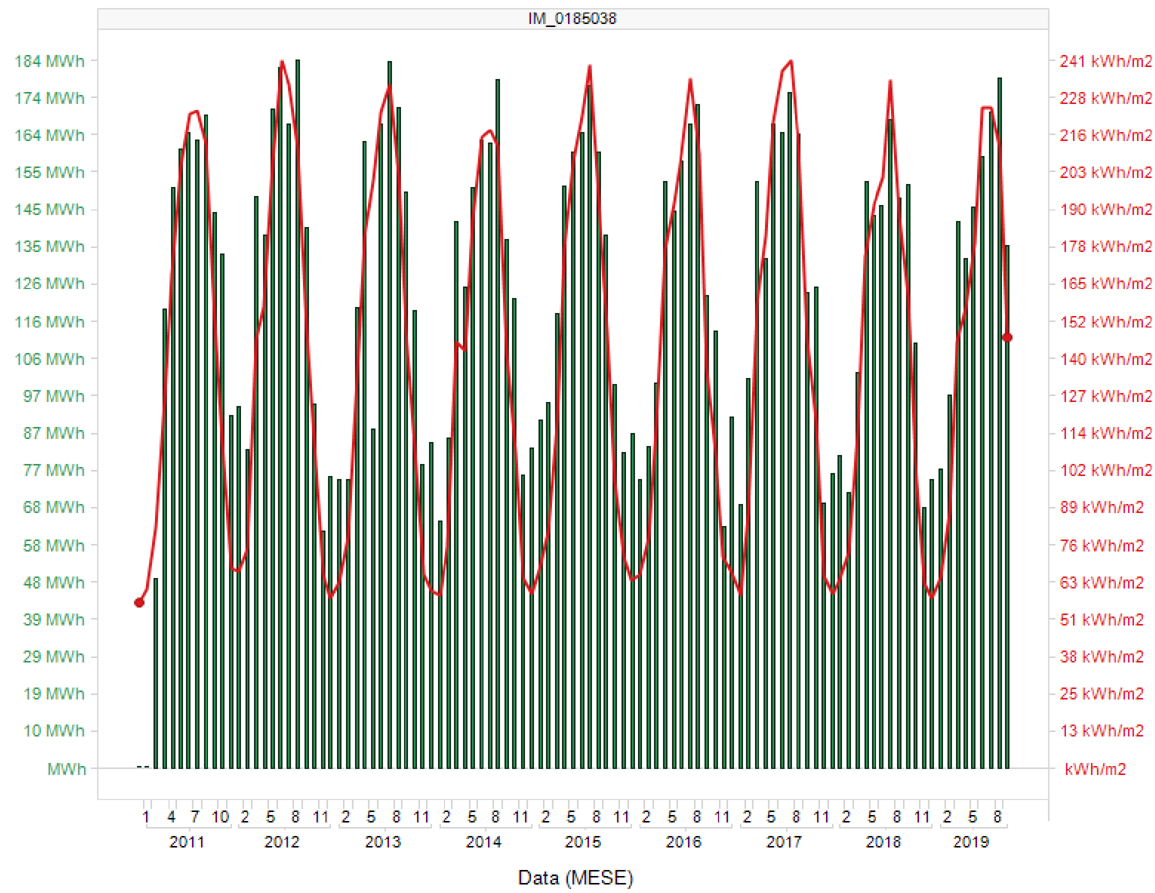

Figure 17 Real Energy Produced by Spietri Plant

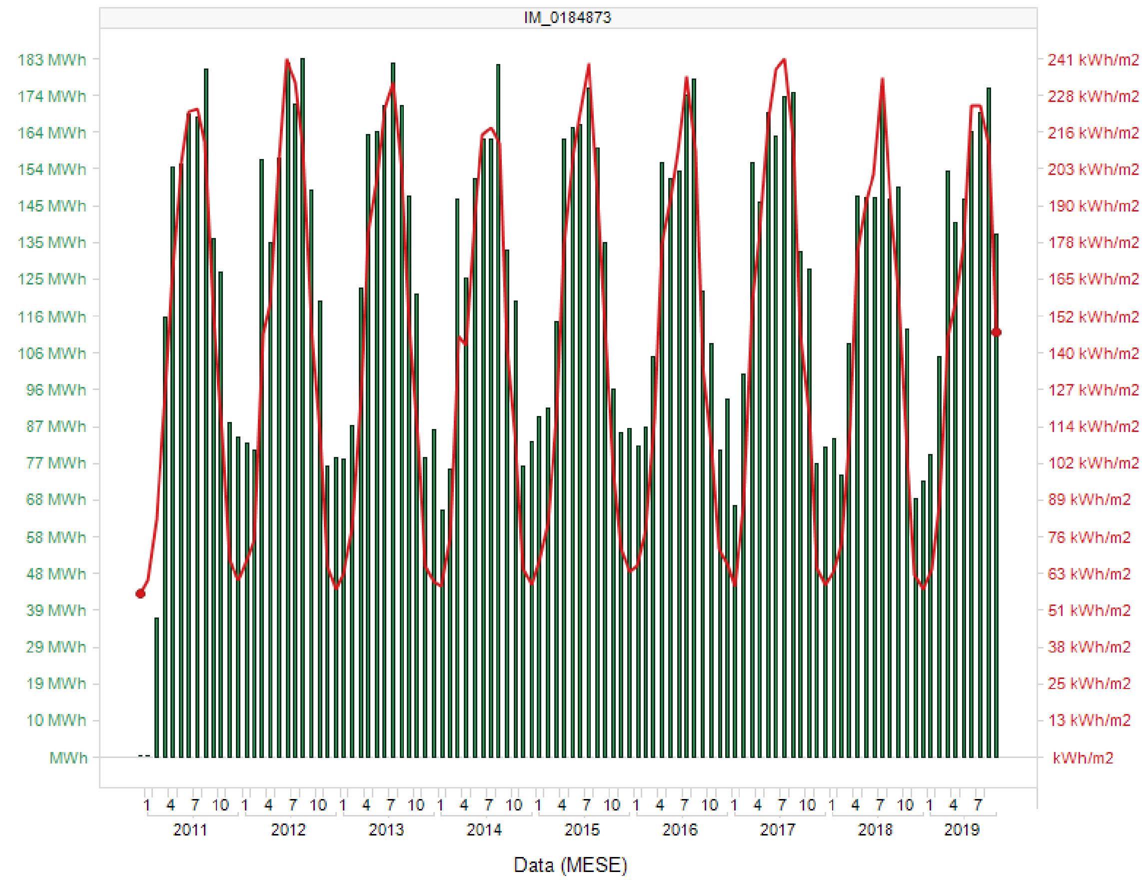

Figure 18 Real Energy Produced by Le Forche Plant

Appendix 2

The Table 20, Table 21 and Table 22 correspond to the whole set of energy market prices of bands 1, 2 and 3 for the Sud region; the values were used to graph Figure 12 and Table 19. Same data was useful in the subchapter 4.3 to set the Pz and run the NPV for the 250 kW plant and be able to do the economic assessment.

Table 20 Energy Market Prices - Band 1 (F1)

Sud Zone Price: Band 1 (F1) [€/MWh]												
Month	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Average**
Jan	124,29	66,37	69,74	87,88	62,72	57,39	56,29	37,16	63,83	50,42	65,38	67,41
Feb		64,25	65,18	84,27	59,22	46,56	51,84	36,40	51,50	56,79	46,45	56,25
Mar	90,81	56,29	69,39	74,66	37,14	24,08	43,76	31,68	39,75	47,87	37,01	50,22
Apr		61,91	68,48	64,58	39,07	21,29	36,07	28,74	42,16	50,10	49,71	46,21
May	102,85	63,01	70,84	74,66	37,14	24,73	41,23	33,70	44,96	57,97	46,58	54,33

Jun		67,30	68,71	64,58	42,85	33,41	47,74	38,32	38,32	60,92	51,06	51,32
Jul	66,55	78,56	71,54	69,88	60,43	38,78	62,95	42,33	47,34	63,29	56,61	59,84
Aug	95,42	87,27	73,26	69,31	51,71	35,69	51,35	34,84	49,20	66,98	48,29	60,30
Sep	73,37	66,70	80,26	64,79	47,06	47,69	47,32	37,59	45,25	66,98	53,79	57,35
Oct	67,35	69,33	80,48	63,86	51,99	49,85	44,55	43,08	48,92	65,59	51,39	57,85
Nov	55,80	56,55	85,21	64,22	57,29	57,68	47,10	51,64	60,58	63,66		59,97
Dec	66,02	63,59	85,91	66,93	64,88	65,10	52,95	50,29	63,25	66,52		64,54

Table 21 Energy Market Prices - Band 2 (F2)

Sud Zone Price: Band 2 (F2) [€/MWh]												
Month	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Average**
Jan	98,66	64,06	68,45	85,66	67,61	60,3	52,92	43,62	57,85	49,67	66,9	65,06
Feb		62,37	68,92	84,36	62,79	54,42	55,21	35,54	50,16	55,46	55,98	58,52
Mar	88,09	62,37	70,52	80,12	59,27	46,15	42,06	34,94	40,89	53,15	45,72	56,66
Apr		65,88	68,93	70,25	59,97	49,05	48,39	34,19	41,77	47,85	47,66	53,39
May	86,42	59,41	72,06	80,12	59,27	50,03	39,75	34,94	41,68	53,25	51,34	57,12
Jun		64,98	68,88	70,25	66,15	47,67	45,46	36,59	36,59	51,97	45,58	53,41
Jul	52,95	68,12	69,66	77,15	69,84	44,39	56,39	38,16	44,93	59,03	48,21	57,17
Aug	81,08	79,1	75,4	77,94	66	47,38	51,59	33,09	48,41	63,69	45,14	60,80
Sep	64,98	70,03	81,5	76	68,85	55,66	47,28	37,59	44,1	63,69	45,43	59,56
Oct	59,26	72,7	85,7	70,68	71,19	57,49	45,58	45,07	41,99	61,08	46,06	59,71
Nov	55,11	62,5	83,88	67,14	67,22	57,55	44,86	50,18	57,78	66,26		61,25
Dec	59,99	62,79	85,52	73,31	63,72	67,8	57,79	50,66	59,27	64,4		64,53

Table 22 Energy Market Prices - Band 3 (F3)

Sud Zone Price: Band 3 (F3) [€/MWh]												
Month	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Average**
Jan	55,92	46	55,69	62,04	47,57	42,73	41,62	32,06	50,17	42,26	55,14	48,29
Feb		48,18	54,14	61,77	46,85	34,65	44,19	29,09	47,28	45,62	45,79	45,76
Mar	57,03	42,78	56,42	53,99	42,52	30,05	35,1	29,23	39,95	41,48	41,98	42,78
Apr		49,81	57,51	55,12	43,36	30,36	37,97	27,64	34,48	33,53	40,56	41,03
May		46,47	60,66	53,99	42,52	37,06	32,74	30,09	31,53	39,9	36,64	41,16
Jun		44,2	59,07	55,12	42,8	37,27	37,06	33,32	33,32	50,45	39,82	43,24
Jul	38,59	54,11	57,7	71,5	56,65	37,47	49,08	32,33	38,24	49,65	40,08	47,76
Aug	53,68	58,14	65,3	73,37	56,82	38,89	45,37	29,61	40,38	57,29	40,6	50,86
Sep	43,19	53,81	67,76	63,16	51,62	42,98	40,22	33,91	38,76	57,29	42,06	48,61
Oct	38,8	49,55	66,35	51,6	49,81	45,12	37,89	41,51	38	58,2	39,72	46,96
Nov	37,04	48,86	63,56	45,16	39,26	40,54	36,54	46,24	48,81	57,14		46,32
Dec	42,73	51,46	65,58	49,82	41,98	47,52	43	46,75	52,69	55,95		49,75

In the other hand Table 23 is an example of the logic used to compute how many times the constraint 1 was accomplished according to the topic planted in subchapter 4.2 and fill the values of the Table 18; this in specific correspond to the case 1 for the F1 band and with a Relative Tariff = 69,99 [€/MWh] (the maximum possible). The restriction was $T_{spet} \geq 2P_z$.

Table 23 Logic Table of Market Prices

Sud Zone Price: Band 1 (F1) [€/MWh]											
Month	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Jan	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	24	0	32	0	0	0
Apr	0	0	0	0	0	21	0	29	0	0	0
May	0	0	0	0	0	25	0	34	0	0	0
Jun	0	0	0	0	0	33	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	35	0	0	0
Sep	0	0	0	0	0	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	0	0

Appendix 3

The Table 24 and Table 25 were used to sketch respectively Figure 13 and Figure 14 to measure the sensitive of the LCOE according to the CAPEX and energy yield drivers. Additionally are presented the Table 26 and the Table 27 just to give information of the less influent drivers on LCOE, mentioned values were not included as figures neither analyzed in the subchapter 4.1.

Table 24. Variation of LCOE according to the CAPEX

1000 kW PV plant			
Variation CAPEX [%]	**CAPEX [€/Wp]**	**LCOE [€/MWh]**	**LCOE Variation [%]**
-10	0,56	31,33	-6,70
-5	0,59	32,46	-3,34
0	0,62	33,58	0,00
5	0,65	34,71	3,37
10	0,68	35,84	6,73
250 kW PV plant			
Variation CAPEX [%]	**CAPEX [€/Wp]**	**LCOE [€/MWh]**	**LCOE Variation [%]**

-10	0,68	38,47	-6,72
-5	0,72	39,86	-3,35
0	0,76	41,24	0,00
5	0,80	42,62	3,35
10	0,84	43,86	6,35

Table 25. Variation of LCOE according to the Energy Yield

1000 kW PV plant			
Variation Yield [%]	**Yield [Wh/Wp/year]**	**LCOE [€/Wp]**	**LCOE Variation [%]**
-11,11	1400	37,78	-12,51
-4,76	1500	35,26	-5,00
0,00	1575	33,58	0,00
1,59	1600	33,06	1,55
4,76	1650	32,06	4,53
250 kW PV plant			
Variation Yield [%]	**Yield [Wh/Wp/year]**	**LCOE [€/Wp]**	**LCOE Variation [%]**
-11,11	1400	46,39	-12,49
-4,76	1500	43,30	-5,00
0,00	1575	41,24	0,00
1,59	1600	40,59	1,58
4,76	1650	39,36	4,56

Table 26 LCOE Variation of the 1000 kW plant

1000 kW PV plant			
Variation OPEX [%]	**OPEX [€/Wp]**	**LCOE [€/MWh]**	**LCOE Variation [%]**
-58,82	0,007	27,66	-17,63
-29,41	0,012	30,62	-8,81
0,00	0,017	33,58	0,00
29,41	0,022	36,55	8,84
58,82	0,027	39,51	17,66
WAAC nom		**LCOE [€/MWh]**	**LCOE Variation [%]**
4,0%		34,27	-2,05
4,5%		33,58	0,00
5,5%		32,37	3,60
6,5%		31,35	6,64
8,0%		30,1	10,36
10,0%		28,83	14,15

Table 27 LCOE Variation of the 250 kW plant

250 kW PV plant			
Variation OPEX [%]	**OPEX**	**LCOE**	**LCOE Variation [%]**
-47,62	0,011	35,31	-14,38
-23,81	0,016	38,27	-7,20
0,00	0,021	41,24	0,00
23,81	0,026	44,2	7,18
47,62	0,031	47,17	14,38
WAAC nom		**LCOE**	**LCOE Variation [%]**
4,0%		42,09	-2,06
4,5%		41,24	0,00
5,5%		39,75	3,61
6,5%		38,49	6,67
8,0%		36,95	10,40
10,0%		35,39	14,19

Finally, in Table 28 is showed an example of the NPV calculation used for the economic assessment of the 250 kW, the table has been cut to show relevant years; from year 1-14 the cash flows include the income by grants and the OPEX as costs, at year 15 the Inverters extra cost is included; at year 21 the grants are over and the income perceived is due to the Pz (which was gradually adjusted as was explained in subchapter 4.3). The Relative Tariff used in this example is 54,93 €/MWh; the one that makes the NPV = 0 at year 20.

Table 28 Example of NPV computation

	Year	Energy [MWh]	E*To [€]	OPEX + Inv [€]	E*To - (OPEX + Inv) [€]	E*To - (OPEX + Inv)/(1+WACC)^t
	1	393,75	21624,75	5250	16374,75	15669,62
	2	390,99	21473,38	5250	16223,38	14856,23
	3	388,26	21323,06	5250	16073,06	14084,77
	15	356,87	19599,30	20250	-650,70	-336,23
	16	354,37	19462,11	5250	14212,11	7027,45
	20	344,55	18922,86	5250	13672,86	5669,35
E*Pz [€]	21	342,14	25042,84	5250	19792,84	7853,55
	22	339,75	25190,81	5250	19940,81	7571,54
	30	321,18	26406,55	5250	21156,55	5648,80