INNOVATIVE INVESTIGATION ABOUT THE PAYBACK TIME OF PHOTOVOLTAIC PLANTS IN ITALY.

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ABSTRACT

Before the end of this decade, PV systems will offer the opportunity for every European citizen to become a producer by exchanging electrical energy with the grid via its decentralized source. This exchange will occur at a competitive price once grid parity is achieved, but at present incentive systems are needed in order that the producer can have revenues. This paper shows that, in the framework of Conto Energia – the photovoltaic incentive system in Italy – the payback time of any photovoltaic plant is decreasing over time regardless of geographic location and in spite of the decrease of incentive rates. The paper considers dynamic irradiation models of the different places where the plant is built, inflation, energy costs, interest rates, construction costs and the different incentives for different investment and profit rate to analyze the payback time of investment in photovoltaic through all versions of Conto Energia.

1. INTRODUCTION

The technologies to produce energy from renewable sources have received great attention in recent years due to increasing price of fossil fuels, concerns for greenhouse gases and climate change. For this reason, there is a need to develop and implement those renewable technologies that can match substantially the increase of energy demand [1].

The photovoltaic (PV) systems have many advantages over other power generation technologies, e.g. they require little maintenance and can operate for long periods without the assistance of any operator. In addition, if necessary, a further generation capacity can be added easily, which makes it suitable for application in remote places [2].

Many countries have initiated different policies for the development of PV in their national electrification plan. In Italy, the evolution of solar incentive system can be seen as a path parallel to the growth of a technology created to generate high-tech renewable energy which has been joined by the need to integrate more and more installations in buildings [3].

Since 2006, the state policy regarding the PV in Italy has been changing through four versions of an incentive system called "Conto Energia", that have updated the rules and rates for PV plant incentives accounting for the dynamics of the PV market. Indeed, the incentives have fostered – in Italy and abroad - an increase in demand for photovoltaic components, thereby creating a competitive market which has led to a decrease in prices of these components, as well as of overall PV plant costs. Fig.1 shows the trend, according to Solarbuzz, of PV module prices over the period [4].

In order to account for this decrease, the incentive rates have been progressively reduced though the four versions of the Conto Energia. In addition, from second Conto Energia on, a bonus for building integration has been introduced, too.

The goal of this paper is the estimation of payback time of PV plants of different sizes and destinations in Italy, considering the time evolution of the incentive mechanism as well as the market economy of the plants. Table I summarizes the incentive rates for all the PV plant sizes considered in the simulations performed in this paper, under the hypothesis that plants up to a peak power of 20 kW are fully integrated, while plants above this size are "non-integrated" [5]. Since the incentive rates from the Conto Energia (CE) were periodically updated over the years, as pointed out above, Table I assumes that the investment is made at the beginning of each version of the CE.

Table II shows the prices of PV modules considered in this paper.

To have, however, a preliminary estimate of the total cost of installation, the paper considers that the commissioning cost of a photovoltaic system is mostly associated with modules, inverter, electrical component, engineering, administrative, building and commissioning [6]. As a first approximation, all these values can be considered constant, excepted those relating to the modules, as they affect a small percentage of the total cost of installation and they remain constant over time. For this reason, the cost of the plant, €plant, is calculated with the following equation (1).

$$\text{€}plant = Modules\ Cost\ [\text{€}/Wp] \times Plant\ Size\ [Wp] \times Index\ \text{"Plant Cost compared to Modules Cost"} \quad (1)$$

Formula (1) enables the calculation of the cost of a given PV plant, on condition that the per-unit power module cost (see Table II) and the plant size are known. The index "Plant

Cost compared to Modules Cost" for the crystalline silicon can be considered equal to a value between 1.5 and 1.9 [7].

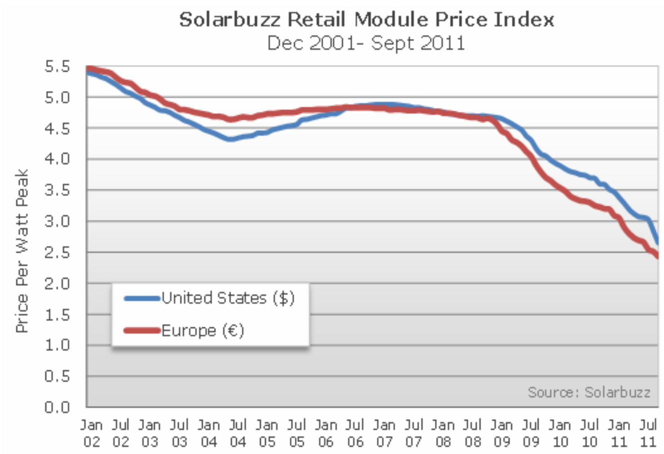

Fig.1. Evolution of the cost of photovoltaic panels in the U.S. and the Eurozone

TABLE I

INCENTIVE RATES CONSIDERED IN THE ANALYSIS FOR DIFFERENT SIZE AND TYPE OF PV PLANTS IN THE FOUR VERSIONS OF THE CONTO ENERGIA (CE)

	Incentive Rate [€/kWh]			
	1°CE	2°CE	3°CE	4°CE
3 kW - Residential	0,489	0,48	0,402	0,387
6 kW - Residential	0,489	0,451	0,377	0,356
10 kW - Residential	0,489	0,451	0,377	0,356
20 kW - Residential	0,489	0,451	0,377	0,356
20 kW - Tertiary	0,445	0,372	0,339	0,319
30 kW - Tertiary	0,46	0,353	0,321	0,306
40 kW - Tertiary	0,46	0,353	0,321	0,306
50 kW - Industrial	0,46	0,353	0,321	0,306
60 kW - Industrial	0,49	0,353	0,321	0,306
70 kW - Industrial	0,49	0,353	0,321	0,306
80 kW - Industrial	0,49	0,353	0,321	0,306
90 kW - Industrial	0,49	0,353	0,321	0,306
100 kW - Industrial	0,49	0,353	0,321	0,306

TABLE II

OVERVIEW OF THE COST OF A PHOTOVOLTAIC MODULE

[€/Wp]	Module Cost	≤3 kWp	>3 and ≤40 kWp	>40 and ≤100 kWp
2006	3,6	1,8	1,6	1,5
2007	3,45	1,8	1,6	1,5
2008	3,25	1,8	1,6	1,5
2009	2,6	2	1,7	1,6
2010	2	2	1,7	1,6
2011 Jan	1,7	2,2	1,9	1,7
2011 Jun	1,5	2,2	1,9	1,7

2. DETAILS ON COSTS AND PRODUCTIONS

The PV plants analyzed in the simulations have been selected having as a reference three different kinds of users, having quite different annual energy demand [8]:

- 4'500 kWh/y (residential or "family size" user: this is typically a Southern Europe value, in USA this quantity can be even 10 times more);
- 30'000 kWh/y (tertiary user: it refers to a shop or an office, without massive use of electrical motors and/or refrigerators);
- 75'000 kWh/y (industrial user of limited size, typically a family-operated producing unit).

Having set these demands, the sizes (in kWp) of the PV plants analyzed in the simulations have been chosen based on two alternative hypotheses:

1. the PV plant is sized in a net-metering environment, to fully satisfy the energy needs of the user;
2. the PV plant is sized in a net-metering environment, but it is over-sized, so that the energy surplus is sold to the network.

It has been noted that the energy demand of each PV system, in first approximation, grows linearly with the peak power on which the facility is designed. For this reason, the energy demand of each plant for other cases of interest can be calculated through linear interpolation, as shown in Fig.2.

TABLE III

TYPES OF PV PLANTS CONSIDERED IN THE SIMULATIONS

Need (kWh)	Type of PV Plant	Power (kW)	
		sized on the need	oversized
4'500	Residential	3 kWp 6 kWp	20 kWp
30'000	Tertiary	20 kWp	
75'000	Industrial	50 kWp 70 kWp	100 kWp

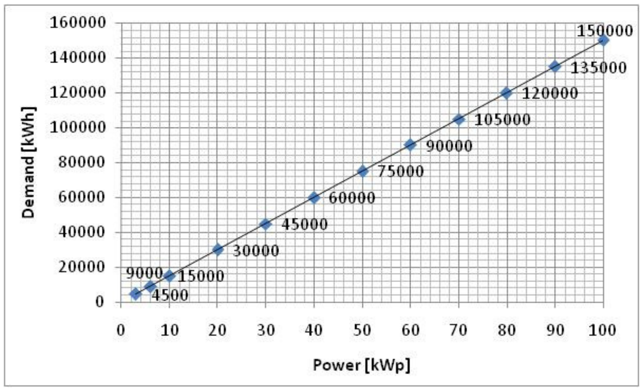

Fig.2. Linear interpolation of the needed energy

The calculation of payback time requires that the sum of annual revenues (energy sale at the incentive rates, plus energy savings per year in the net-metering regime, minus operating and maintenance costs) is related to the investment for building the plant.

As to energy sale, since the incentive rates set by the four versions of the Conto Energia are constant over twenty years, an accurate evaluation of the payback time requires that the rate of inflation over the payback time is considered by updating the annual revenues at the current monetary value through a proper inflation rate; for simplicity the simulations herein consider a constant inflation rate over the payback time.

As to the cost of maintenance, operation and electrical energy supplied by the grid in the net-metering regime, the payback time calculation should take into account both the inflation rate and the likely cost increase over the years. Since both cost increase and inflation have stochastic trends, dependent on external variables and difficult to calculate, here in a global vision these two factors are considered to offset each other in the average return time. Therefore, electricity prices are taken constant and equal to 0.18 €/kWh for residential users, 0.16 €/kWh for commercial users, 0.15 €/kWh for industrial users; moreover, the costs of maintenance and operation are considered equal for each user and respectively equal to 22 €/year/kWp and 61 €/year/kWp.

The production of each photovoltaic system is highly dependent on its geographical location, climatic conditions in the years considered and efficiency of the different plants. As far as these factors are concerned, the following considerations have been made here:

1) geographical location has a large influence on the production of electricity due to the spherical shape of the Earth surface. Thus, in order to have reference values of irradiation, the Italian soil has been divided into three different macro-areas, Northern Italy, Central Italy and Southern Italy, selecting for each area a reference location that is barycentric with respect to the area itself;

2) weather is a stochastic variable, whose prediction is extremely difficult. Thus, we have used the statistical data of irradiation in recent years in the reference locations, so as to be able to work with mean values;

3) efficiency is also a stochastic variable in the case considered. Leading PV companies in the crystalline silicon sector offer efficiency fairly constant in the early years of the investment, by guaranteeing e.g. no loss of efficiency in the first 10 years, and no more than 10% loss of efficiency after 15 years. Thus, efficiency can be assumed constant during the pay-back time period.

In conclusion, it is considered an annual average production of 1050 kWh/kWp for Northern Italy, 1250 kWh/kWp for Central Italy and 1480 kWh/kWp for Southern Italy.

3. RATE OF PROFIT

The rate of profit is an instrument that allows to compare investments with different initial cost [9]. It considers the discounted cash flows from interest, inflation and rising energy costs. Given that the interest rate is compensated by the increase in energy prices, also the incentives and annual revenue resulting from the sale of energy are constant, hence the discounted cash flow can be calculated using the equation (2):

$$VAN = \sum_{j=1}^{k} \frac{R}{(1+i)^j} - C_0 \tag{2}$$

Once discounted cash flows are known, the rate of profit IP can be calculated by the equation (3).

$$IP = \frac{VAN + C_0}{C_0} \tag{3}$$

4. CASE STUDIES

The case studies presented in this paper consist in multiple models that simulate the behavior of cash flows. As shown in Table III, it is hypothesized that, in some models, PV systems are sized according to the energy demand, and, in other models, that the investor decides to oversize the system. In this case the investor increases the return period, but achieving a greater flow of cash at the end of plant life (case "oversized") [10].

The sized plants were selected for residential, commercial and industrial users, whose load curves change significantly. To execute the calculation of the annual cash flows of the plants the following considerations have been implemented:

• The production of average energy per year is known, and it is based on the geographical location where the plant is located, as already discussed.

• The energy produced per year is given by an annual per-unit power average energy production multiplied by the power of the plant taken into consideration.

• The cost of the plant is obtained from the above equation (1), with the values tabulated in Table II.

• Energy savings per year are given by the energy produced yearly multiplied by the energy price, that depends on the type of user: 0.18 €/kWh for residential users, 0.16 €/kWh for commercial users, 0.15 €/kWh for industrial users, as pointed out above.

• The per-unit power operation and maintenance costs per year - regarded as fixed and equal for each user - are taken respectively as 22 €/year/kWp and 61 €/year/kWp, as pointed out above.

• The incentive rates are known from the above Table I.

• The annual revenue from the incentive system is given by the energy produced per year multiplied by the relevant incentive rate.

• The annual budget is the sum of annual revenues from energy sale at the incentive rates plus energy savings per year, minus operating and maintenance costs.

• The payback time, through inflation, is calculated by actualizing cash flows over the years by the inflation. The inflation rate is considered constant and equal to 5%.

4.1. Photovoltaic plant of 3 kW

The 3kW plant size is the type of system most commonly used by residential users. This choice lies in the small investment costs and the small occupied soil. In fact, these systems are generally built on the roofs of buildings, where the compactness of the components is the critical parameter.

In Fig.3 the payback times resulting from the model are shown as an histogram. The return times, rather long in period of First CE, declined with the successive versions, regardless of geographic location of the plant. Moreover, an investment in Southern Italy - where with the 4th CE in 2011 the Pay-Back period is equal to 4.4 years - has a payback period less than the same investment made in the North. In fact, in Northern Italy at the same time the payback time was 6.4 years.

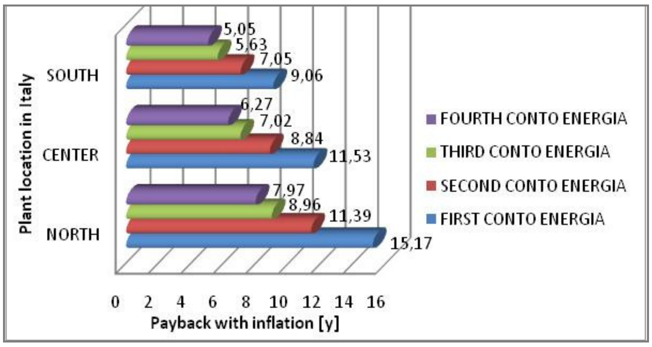

Fig.3. *Payback time vs. the various CEs and areas for a 3kW residential plant*

Fig.4 shows in one single line diagram as the payback time, the incentive rate and the plant cost (normalized to that relevant to the 1st CE) have changed for different geographic locations with the various versions of the CE. It can be argued that the gap in payback time between North and South has decreased with the decrease in the price of PV plants.

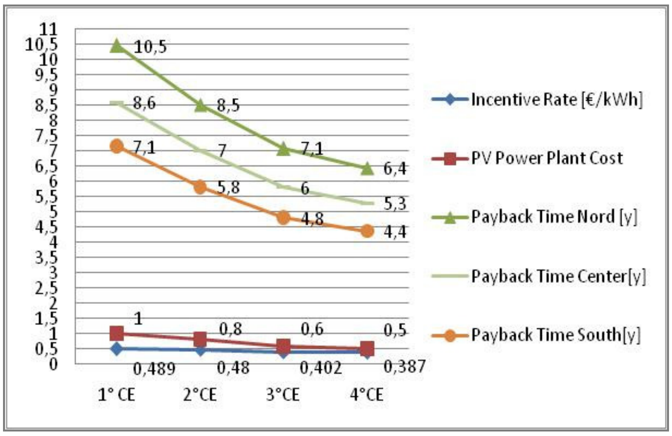

Fig.4. *Payback time, incentive rate and plant cost (normalized to that relevant to the 1st CE) vs. the various CEs and areas for a 3kW residential plant*

4.2. Photovoltaic plant of 6 kW

The 6kW systems are generally installed in residential buildings, but with energy demand and free space availability on the roof slightly higher than in the 3 kW case.

Fig.5 and Fig.6 show the results of the simulations run in histogram and in line diagram form, respectively, similarly to Figs. 3 and 4. As in the previous case, the time of return reduces with the decrease of the investment and latitude for each version of the CE.

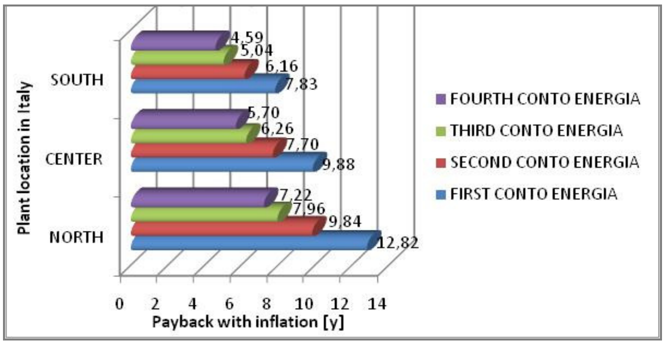

Fig.5. *Payback time vs. the various CEs and areas for a 6kW residential plant*

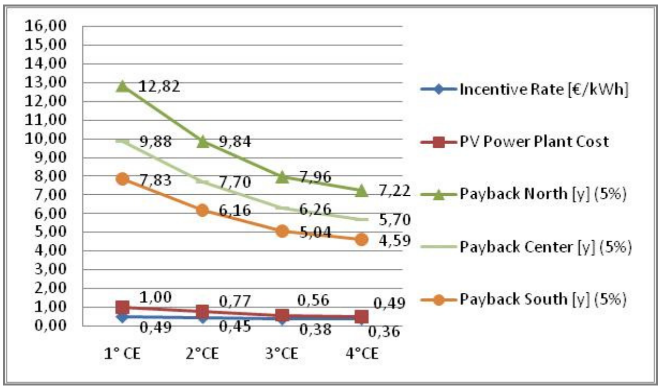

Fig.6. *Payback time, incentive rate and plant cost (normalized to that relevant to the 1st CE) vs. the various CEs and areas for a 6kW residential plant*

4.3 Photovoltaic plant of 20 kW, oversized

The plants of power of 20 kW are generally used in two separate cases. A first possible case is a residential one characterized by consumers with extensive residential areas, high willingness to invest and a lot of space on the roof. The results for this particular case are shown in Fig. 7 and Fig. 8.

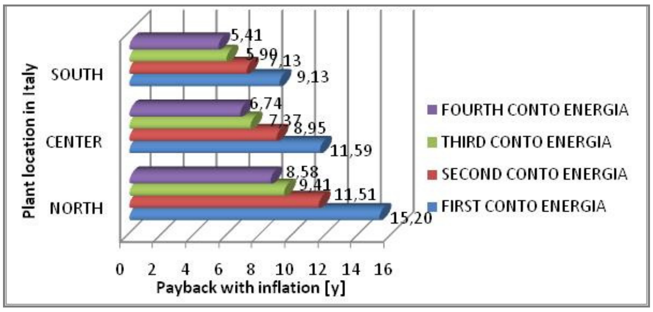

Fig.7. *Payback time vs. the various CEs and areas for a 20 kW residential plant, oversized*

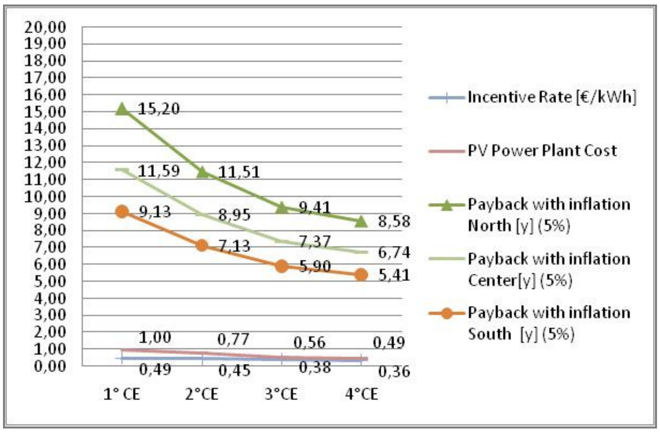

Fig.8. *Payback time, incentive rate and plant cost (normalized to that relevant to the 1st CE) vs. the various CEs and areas for a 20kW residential plant, oversized*

The Figures show, as widely expected, a payback time greater than the cases discussed above due to a higher initial investment, that is only partially compensated by the revenues from energy withdrawal by the distribution utility.

4.4. Photovoltaic plant of 20 kW

A second possible case of 20 kW plant is a tertiary one. Indeed, 20 kW is often the typical size for the power users in the tertiary sector. In this case, the plant is sized on a need of 30000 kWh (see Table III), thus all the energy that flows from the device to the counter, is sooner or later consumed by the user, thus it can be entirely sold to the grid at the incentive price. As a consequence, as Fig.9 and Fig.10 show, the payback time is less than in the previous 20 kW case.

4.5. Photovoltaic plant of 50 kW

Industrial users may have widely varying requirements depending on their plant size, working hours and type of work that is done. Referring to industries with medium/small consumption, i.e. 75000 kWh as listed in Table III, it was assumed, first of all, that they have chosen to install a photovoltaic plant whose peak power is equal to 50 kW. The results are shown in Fig.11 and Fig.12.

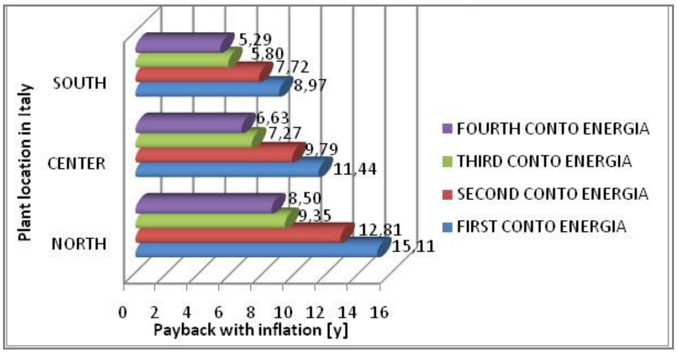

Fig.9. *Payback time vs. the various CEs and areas for a 20kW tertiary plant*

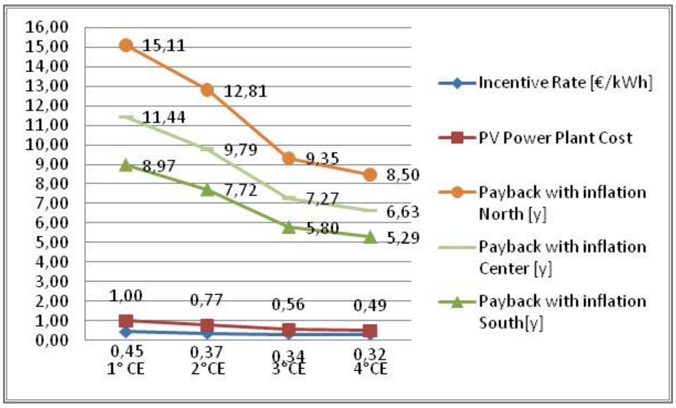

Fig.10. *Payback time, incentive rate and plant cost (normalized to that relevant to the 1st CE) vs. the various CEs and areas for a 20kW tertiary plant*

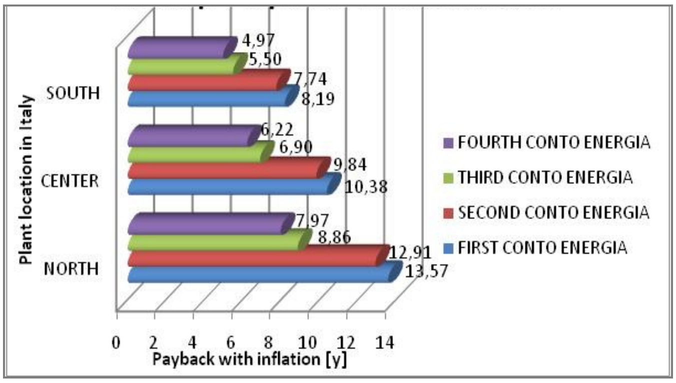

Fig.11. *Payback time vs. the various CEs and areas for a 50kW industrial plant*

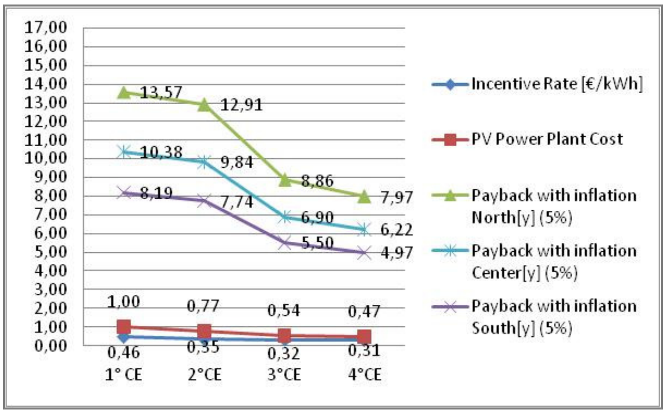

Fig.12. *Payback time, incentive rate and plant cost (normalized to that relevant to the 1st CE) vs. the various CEs and areas for a 50kW industrial plant*

4.6. Photovoltaic plant of 70 kW

Another typical size for the industry is 70 kW. It is generally dedicated to large size plants with large availability of money and with a lot of unused space. The results are in Fig.13 and Fig.14.

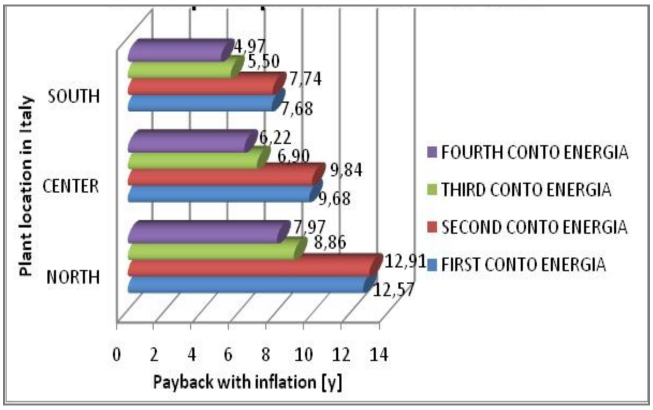

Fig.13. *Payback time vs. the various CEs and areas for a 70 kW industrial plant*

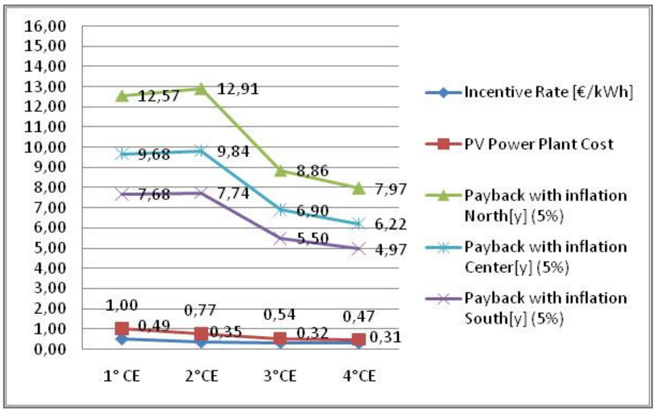

Fig.14. *Payback time, incentive rate and plant cost (normalized to that relevant to the 1st CE) vs. the various CEs and areas for a 70kW industrial plant*

4.7. Photovoltaic plant of 100 kW, oversized

The last plant proposed in this analysis refers to a medium sized industry, who decided to make a sizeable investment in photovoltaics. The power given in this analysis is to 100kW peak, that is oversized with respect to a demand of 75000 kWh. Fig.15 and Fig.16 show the results.

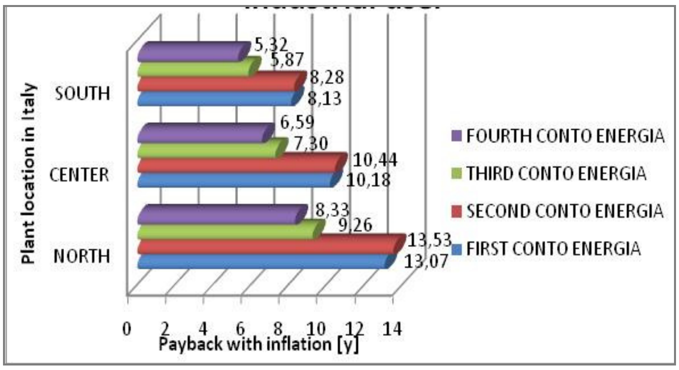

Fig.15. *Payback time vs. the various CEs and areas for a 100kW industrial plant, oversized*

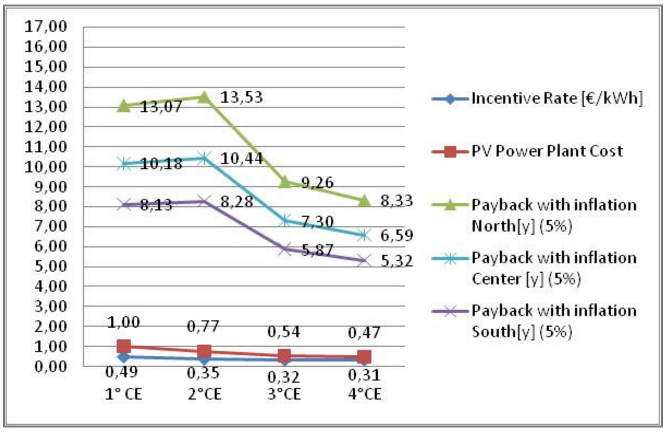

Fig.16. *Payback time, incentive rate and plant cost (normalized to that relevant to the 1st CE) vs. the various CEs and areas for a 100kW industrial plant*

4.8. Comparison between the sizes

As it can be seen from Fig. 17, Fig. 18 and Fig. 19, irrespective of the CE in the framework of which the investment was done, the 6 kW plant has the lowest Pay-Back time. This result is also supported by Table V, which shows the rate of profit IP (see equation (3)) for all investments considered, in each version of CE. The Table shows that:

- for all the geographic areas, the size of the installation with the highest rate of profit is 70 kW for the 1st CE, 6 kW for the 2nd, 3rd and 4th CE;
- for all the geographic areas, the size of the installation with the highest rate of profit among the oversized plants is 100 kW for the 1st, 3rd and 4th CE, 20 kW for the 2nd CE;
- the system with highest rate of profit over all analyzed periods, types of plants and geographic areas is the 6 kW plant in Southern Italy under the 4th CE [11].

It can be argued that, regarding the facilities designed for the needs of users, the first incentives were structured in such a way that – among the plant sizes considered here – the highest profit rate occurred for plant sizes of 70 kW [12]. Later on, the second CE has changed this policy in such a way that in the relevant period the systems with the highest profit rate were the 6 kW ones. The third and fourth CE have obtained the same results as the second, but the gap in terms of profit between different sizes has decreased.

In addition, despite lower and lower incentives, the rate of profit has grown from the 1st to the 4th CE: in particular, from 1.34 to 2.1 for the 6 kW peak plant size in Northern Italy, from 1.96 to 3.1 for the 6 kW peak plant size in Southern Italy. Consequently, the profitability of the investment has almost doubled when passing from the 1st to the 4th CE.

Considering the purely hypothetical case that an investor has never-ending money, the investment that would give the greater profit is given by the 6 kW plant.

5. CONCLUSIONS

The increasing rate of profit, accompanied by a continuous reduction of turnaround time, showed that, regardless of plant size selection and type of user, the profitability of the investment in building a PV plant has progressively grown from the 1st to the 4th CE.

Contrary to what might appear from a superficial analysis, the progressive decrease of the incentives given by Conto Energia did neither affect the return period nor contrast the actual validity of the investment; on the contrary, they continued pushing photovoltaic technology to a greater competitiveness compared to non-renewable energy sources [13].

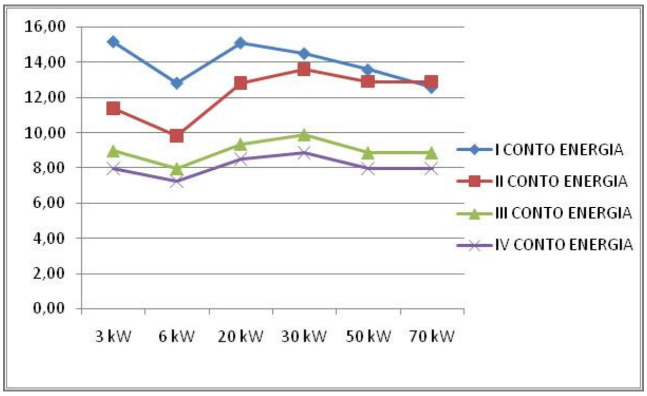

Fig.17. *Scatter plot of the payback time in years (ordinate axis) for different users according to the various CEs in Northern Italy*

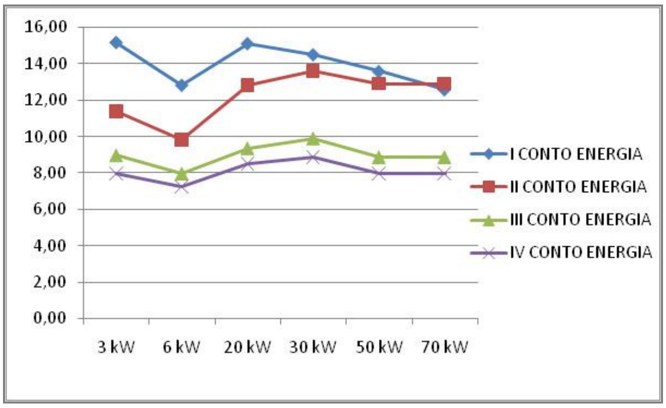

Fig.18. *Scatter plot of the payback time in years (ordinate axis) for different users according to the various CEs in Central Italy*

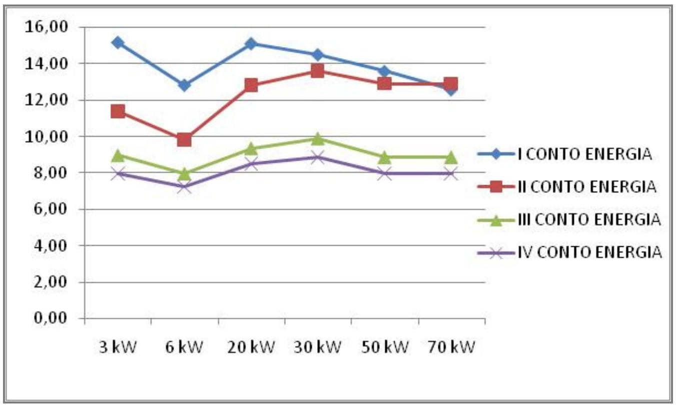

Fig.19. *Scatter plot of the payback time in years (ordinate axis) for different users according to the various CEs in Southern Italy*

This work has also shown that, when considering inflation, the gap in the Pay-Back time between Northern Italy and Southern Italy is wide, because of the higher irradiation and the relevant higher production of energy from photovoltaic cells in the South than in the North. To exploit this gap at best and allow investing where there is a wider economic benefit, a priority task – that the managers of the national network must pay attention to – will be for example increasing the meshing of the network in the southern areas.

TABLE V
PROFIT RATE FOR DIFFERENT SIZES

	I CONTO ENERGIA			II CONTO ENERGIA		
	NORD	CENTRO	SUD	NORD	CENTRO	SUD
3 kW	1,19131423	1,44863579	1,74455559	1,46191314	1,77826155	2,14206223
6 kW	1,34026457	1,62971527	1,96262504	1,63404389	1,98986537	2,39906008
20 kW-O	1,1896678	1,442655	1,73359028	1,45051529	1,76184499	2,11987414
20 kW	1,19483605	1,45662901	1,75769092	1,34095639	1,64095168	1,98594626
50 kW	1,28660783	1,56816147	1,89194816	1,33354638	1,63491618	1,98149144
70 kW	1,35930405	1,6547046	1,99441522	1,33354638	1,63491618	1,98149144
100 kW-O	1,3216751	1,59198968	1,90285144	1,28959911	1,56167073	1,8745531
	III CONTO ENERGIA			IV CONTO ENERGIA		
	NORD	CENTRO	SUD	NORD	CENTRO	SUD
3 kW	1,75970409	2,14756539	2,59360589	1,93485257	2,36309943	2,85558333
6 kW	1,93627253	2,36608374	2,86036664	2,09802404	2,56677806	3,10584518
20 kW-O	1,69244919	2,06315172	2,48945963	1,82169093	2,2234551	2,68548389
20 kW	1,70130392	2,08635921	2,52917279	1,83631763	2,2552228	2,73696375
50 kW	1,77467912	2,18088681	2,64802565	1,93433053	2,38003782	2,8926012
70 kW	1,77467912	2,18088681	2,64802565	1,93433053	2,38003782	2,8926012
100 kW-O	1,7143948	2,08041293	2,50133379	1,8660083	2,26616743	2,72635043

1. REFERENCES

[1] Morrison, A.J.: Global Demand Projections for Renewable Energy Resources, Proc. 2007 IEEE Electrical Power Conference (EPC 2007), Calgary, AB, Canada, Oct. 25th-26th 2007, pp. 537–542.

[2] Liu Yan: On the value composition and pricing model of renewable energy source, Proc. 2010 International Conference on Management Science and Engineering (ICMSE), Nov. 24th-26 th 2010, pp. 200 – 204.

[3] Lubritto, C.; Petraglia, A.; Vetromile, C.; Caterina, F.; D'Onofrio, A.; Logorelli, M.; Marsico, G.; Curcuruto, S.: Telecommunication power systems: Energy saving, renewable sources and environmental monitoring, IEEE 30th International Telecommunications Energy Conference (INTELEC 2008), Sept. 14th-18th 2008, pp. 1-4.

[4] http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices

[5] Mazzanti, G.; Malmusi, E.: The so-called “Conto Energia”: An effective incentive to the use of photovoltaic energy in Italy, Proc. 2011 IEEE International Conference on Clean Electrical Power (IEEE ICCEP 2011), Ischia (Italy), June 14th-16th 2011, pp. 763-768.

[6] Yan, H.; Zhou, Z.; Lu, H.: Photovoltaic industry and market investigation, Proc. 2009 International Conference on Sustainable Power Generation and Supply (SUPERGEN '09), April 6th -7th 2009, pp. 1–4.

[7] http://www.pvxchange.com/request/Default.aspx?langTag=en-GB

[8] Ge, X.; Xu, W.; Hong, B.; Zhao, B.; Tong, H.: Research on utilization ratio of grid-connected distributed solar photovoltaic sources, 2010 China International Conference on Electricity Distribution (CICED), Sept. 13 th-16th 2010, pp. 1-6.

[9] Matsubayashi, Y.: Exchange Rate, Expected Profit And Capital Stock Adjustment: Japanese Experience, Japanese Economic Review, Jun. 2011, Vol. 62 Issue 2, pp. 215-247.

[10] Mazzanti G.; Santini E.; Zaccagnini Romito D.: Towards Grid Parity of Solar Energy in Italy: the Payback Time Trend of Photovoltaic Plants during the Last Years, to be published on Proc. 2012 IEEE Power Engineering Society General Meeting (IEEE PES GM 2012), San Diego, California (USA), July 22nd-26th 2012.

[11] Pinkse, J.; van den Buuse, D.:, The Development and Commercialization of Solar PV Technology in the Oil Industry, Energy Policy, January 2012, Vol. 40, Issue 1, pp. 11-20.

[12] Milstein, I.; Tishler, A.: Intermittently Renewable Energy, Optimal Capacity Mix and Prices in a Deregulated Electricity Market, Energy Policy, July 2011, Vol. 39, Issue 7, pp. 3922-3927.

[13] Gowrishankar, V.; Hutton, D.; Fluhrer, C.; Dasgupta, N.: Making Photovoltaic Power Competitive with Grid Power, Proc. 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion, May 2006, Vol. 2,pp.2532–2535.