WHAT …..IF …? BETWEEN IMAGINATION AND ENERGY POLICY

<u>Brief considerations on optimizing the producibility of small photovoltaic system with current technologies as well as on related market emerging aspects</u>

R. Morelli IEng MIET – TCM A – AICE / ICEC ; F. Altavilla – GREEN HOUSE SRL G.Manager

The following considerations arise from the examination of some actual offers for photovoltaic systems for domestic use in the Lazio Region (Italy), reflecting on the possibility of:

- optimizing the producibility and economic convenience of a photovoltaic system with current technologies; and
- improving the information and awareness aspects, on the technology available as well as on actual commercial conditions of market for end users of the aforementioned systems.

This appears necessary at a time of real crisis in the energy sector with energy prices that have reached levels of non-sustainability for many families and which have substantially contributed to determining objective obstacles to projects for the diffusion of electric cars as well as energy transition from primary fossil origin to renewable origin.

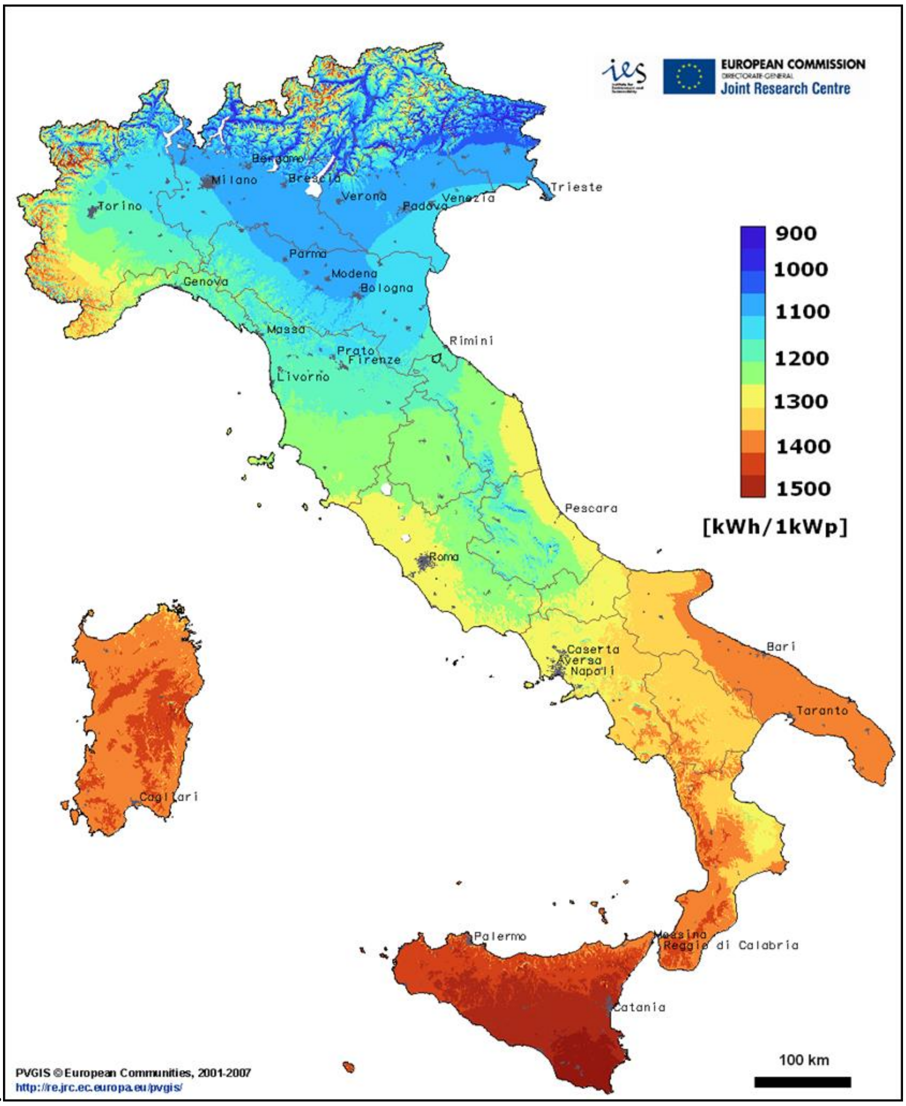
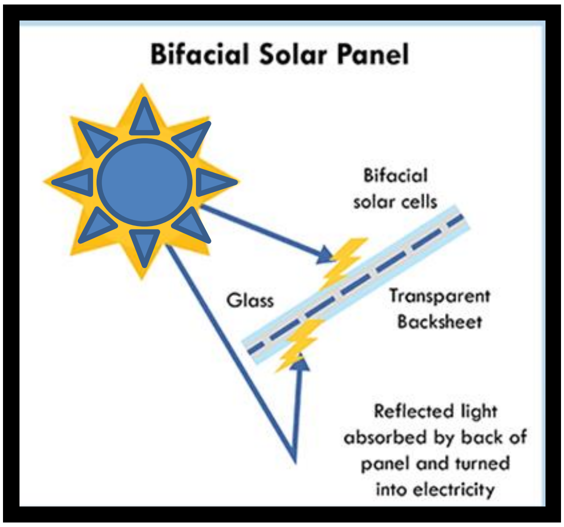


Fig. 1

Literature data indicate that today modern photovoltaic collectors have an average efficiency of around 15%, with a lower performance in amorphous silicon panels, where we have about an efficiency of around 9%, up to the more expensive and advanced modules in mono-crystalline silicon with an average efficiency of approximately 20%. Peak values of up to 23.5% are present in recent offers where such an efficiency value is included among the guaranteed benefits.

The most recent bifacial photovoltaic panels, based instead on a bifacial cell and a transparent film on the back, using both the incident light on the front side and on the back side, can reach an efficiency of up to 30%. Finally, although the possibility of perovskite panels seemed to promise a general reduction in costs, but with efficiency around 21.5%, there have been recent announcements in the media that an efficiency of 33.9% of a single cell has been achieved in tandem photovoltaic system, i.e. made of silicon and perovskite[1].



Fig, 2

Producibility (in kWh/kW) improvements could also be achieved with more accurate orientation of photovoltaic panels. But this path seems more complex than one might think.

As it is known, the average annual unit producibility of a photovoltaic system depends first and foremost on the geographical location in which the system is located, and is expressed in kWh/kW, i.e. in kilowatt hours that can be produced for each kilowatt of nominal power of the system. With the technologies available today, except for concentration or research systems, the values indicated above in the EU/JRC map must be precautionarly considered as the maximum extractable energy (in kWh) from each kW(peak) of installed power.

In our latitudes, it is assumed as a common practice that the modules are oriented exactly to the South and inclined by approximately 30°-35° to the horizontal (the exact inclination, also called "tilt", depends on the geographical latitude of the pv plant site).

Sometimes, even the inevitable effects of shading on a specific site could make some checks necessary. For the optimal positioning of large photovoltaic systems, real preventive simulation campaigns could be carried out on test panels, equipped with solar-meters, to detect power measurements over a long period of time (annual and/or seasonal cycles) and optimize the exposure parameters of the photovoltaic panels. Or evaluate the convenience of adopting systems with tracking of the maximum power point, which varies depending on the time of day, the season as well as brightness and other atmospheric parameters, such as cloud cover, humidity, suspended particles, temperatures, etc. This translates into the need for complex systems to vary

[1] Ref. https://www.dday.it/redazione/47455/celle-fotovoltaiche-nuovo-record-efficienza-33-punto-9-cella-tandem-perovskite

the angles and therefore the spatial orientation of the panels in real time. Systems that are not always economically convenient, also because environmental conditions are changeable and not entirely predictable. Thus, even for large systems, mediation compromises are often made.

The situation is not very different for medium and small systems, especially those for domestic production, where customary practices are used which lead to a fixed installation. So that also in such a case within certain limits it could be optimized by choosing panel orientation angles that vary at least depending on the geographical location and local conditions of the installation site. In theory, also in this case it would be possible to carry out inspections on the site where the panels are positioned and with a luminance (lux) measurement, at least verify the expected producibilities reported above in the map, then converting the lux detected into W/m2. For this purpose, equipment available on the market at affordable prices[2] can be useful, or even with smartphones equipped with applications available on GooglePlay[3] that allow you to detect luminance measurements in lux and - since it is sunlight - convert this value into W/m2, remembering that:

Lux (symbol: lx) is the unit of illuminance, or luminous flux per unit area, in the International System of Units (SI). It is equal to one lumen per square meter. In photometry it is used as a measure of the intensity, perceived by the human eye, of the light that hits or passes through a surface.

There is no simple conversion, it depends on the wavelength or colour of the light. However, for the sun there is an approximate conversion of 0.0079 W/m2 per Lux. For example, to insert the numbers: if we read 75,000 Lux on a solar sensor, we convert that reading to W/m2 as follows: 75,000×0, 0079=590 W/m^2.

In any case, these are checks that should be carried out over a long time, which require a waste of resources and which up to now do not yet appear to be widely practiced, because evidently the "game is not worth the candle".

If the bifacial and tandem photovoltaic systems, made of silicon and perovskite, keep their promises, a real drop in the prices of existing stocks for the previous less competitive technologies can be expected on the market (certainly for the amorphous silicon panels, but perhaps also for the first types of mono-crystalline). This will necessarily lead to more stringent controls in the final testing phase of the systems assembled on a specific site.

At the moment, examining catalogues of the panels utilised and their technical characteristics stated in the offers examined, it is not uncommon to come across diagrams of the following type where an extension of the life cycle is noted, covered by guarantees on offer, from 20-25 years to 30 years . Furthermore, it’s possible to note - together with an improvement in performance in guaranteed efficiency that exceed the traditional 20% - a smaller drop in performance over time (Fig. 3).

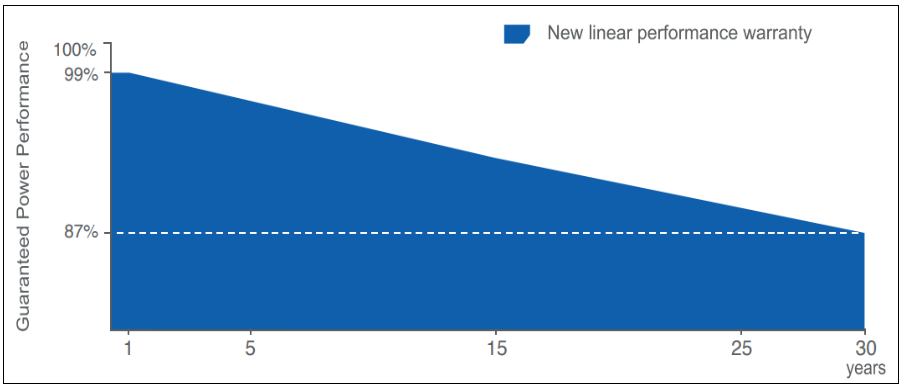


Fig.3

[2] e.g.https://amzn.eu/d/1T3LtOH
[3] e. g. https://play.google.com/store/apps/details?id=solarradiationmeter.orjasolution.app

So on a system with a 30 year life cycle an average of 93% of the rated peak power can be expected due to aging. However, it is known that there is a drop in performance also linked to the effect of temperatures which should be considered especially in very hot sites, although at the moment the offers formulated do not highlight this.

In the best offers, the price levels of the assembled photovoltaic systems also show advantageous improvements for end users and also for market penetration, one of the most important elements that could favour the energy transition. Below is a table (Tab. 1) with prices and conditions present in one of the best offers examined for systems intended for family or small community use.

ACTUAL OFFER OF PHOTOVOLTAIC SYSTEMS MAY 2024 – (Latium Region - Italy)				
Photovoltaic System Description	String Inverter	Hybrid Inverter without Battery	Hybrid Inverter Battery 5 kW/h	Hybrid Inverter Battery 10 kW/h
7 panels 430 Wp total 3 kWp 1 single-phase inverter 3 kW Required surf. area approx 14 m²	€ 5.000	€ 6.400	€ 9.000	
10 panels 430 Wp total 4,3 kWp 1 single-phase inverter 4 kW Required surf. area approx 20 m²	€ 5.600	€ 6.900	€ 9.500	€ 11.800
12 panels 430 Wp total 5,16 kWp 1 single-phase inverter 5 kW Required surf. area approx 24 m²	€ 6.100	€ 7.400	€ 10.000	€ 12.300
14 panels 430 Wp total 6 kWp 1 single-phase inverter 6 kW Required surf. area approx 28 m²	€ 6.600	€ 7.900	€ 10.500	€ 12.800
24 panels 430 Wp total 10,32 kWp 1 single-phase inverter 10 kW Required surf. area approx 48 m²	€ 9.500	€ 11.800	€ 14.900	€ 17.200
47 panels 430 Wp total 20,21 kWp 1 single-phase inverter 20 kW Required surf. area approx 94 m²	€ 17.400	€ 19.900	€ 23.000	€ 25.200
Inclusions : inverter and batteries with 10 years warranty; photovoltaic modules with 30 years guarantee on performance; prices with 10% vat included - design and installation; permits practices included; installation within 2 weeks 50% tax deduction				

Tab. 1

Based on the technical-economic data deduced from the best offer, the following table is obtained (Tab. 2). From it it’s possible to calculate (under the hypothesis of "constant prices 2024"), for each power class of a photovoltaic system, the ratio between Investment and the Overall lifecycle production expressed in kWh. This ratio represents the Life Cycle Cost Share per kWh produced due to the Investment expressed in c.€ (2024)/kWh. With the data from the aforementioned ratio we obtain the graph in Fig. 4 which clearly shows how:

- the impact of the investment on the cost of the kilowatt hour produced is modest, if compared to the prices of kWh on the national electricity market, since it is a few euro cents for each kilowatt hour produced;
- this incidence decreases as the power of the installed system increases and becomes negligible for the power of large installations;
- moreover, the best-fit function shown in the graph (which has a high coefficient of determination) allows us to estimate at which power level this ratio reaches a pre-established value, under the given technical-economic conditions.

Installed Power	Investment (constant price 2024)	Life Cycle Average Producibility	Lifecycle	Average decay factor	Overall lifecycle production	Life Cycle Cost Share per kWh produced due to the Investment
kW_p	€ (2024)	kWh/kW_p	year	-	kWh	c.€ (2024)/kWh
3	9.000	930	30	0,93	83700	10,753
4	11.800	930	30	0,93	111600	10,573
5	12.300	930	30	0,93	139500	8,817
6	12.800	930	30	0,93	167400	7,646
10	17.200	930	30	0,93	279000	6,165
20	25.200	930	30	0,93	558000	4,516

Tab. 2

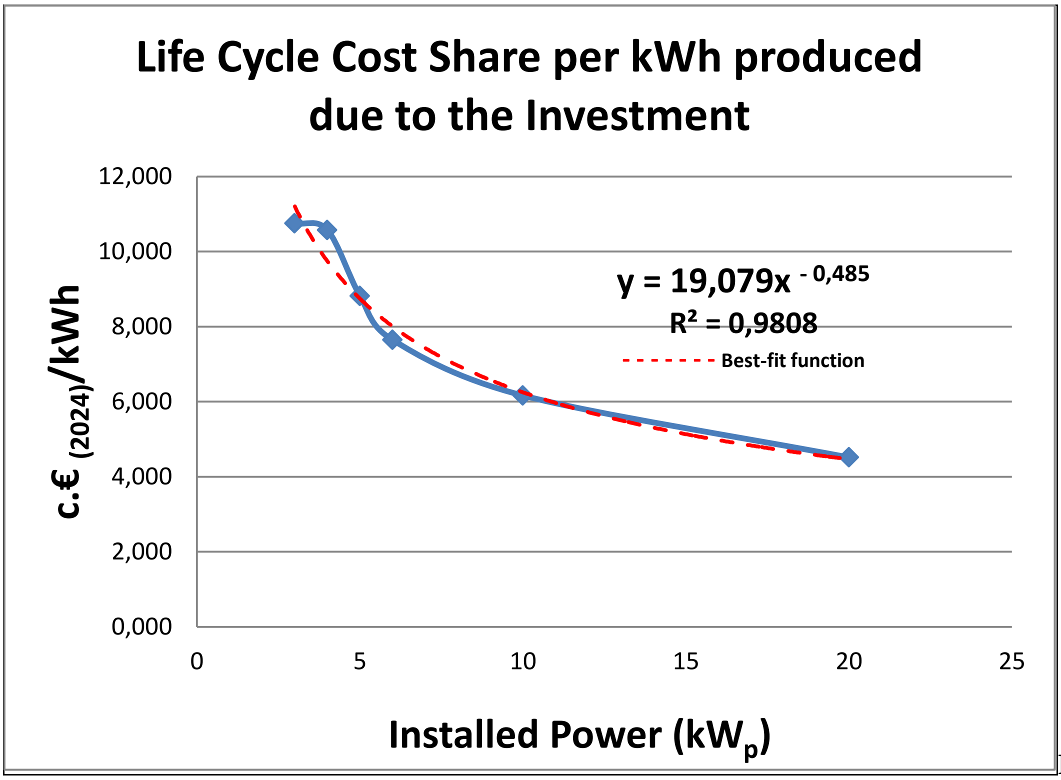


Fig.4

In the cost structure of photovoltaic kWh there is obviously no fuel cost and the annual maintenance costs (especially for small family systems) are considered completely modest over a year (from 40 to 65 €/kWp) as expenses for surveillance and plant operation personnel are also non-existent. But, if maintenance costs are calculated over the entire life cycle, they have a significant influence on the cost of production per kWh. From Tab. 3 we can see how maintenance costs are decisive for the total cost of kWh taking into account the entire life cycle of the system. These total costs of photovoltaic kWh certainly do not encourage end users to join the free national electricity market. Rather, they push them to provide their own photovoltaic equipment, which shows values that are close to half those of the protected electricity market, oscillating between 11 and 15 c.€ (2024)/kWh for the types of systems considered with peak powers ranging from 20 to 3 kWp respectively.

Installed Power	Investment (constant price 2024)	Yearly Maintenace Cost (constant price 2024)	Overall Life Cycle Maintenace Cost (constant price 2024)	Overall Life Cycle Cost (constant price 2024)	Overall lifecycle production	Life Cycle Cost Share per kWh produced due to the Investment	Life Cycle Cost per kWh produced
kW_p	€ $_{(2024)}$	€ $_{(2024)}/kW_p$	€ $_{(2024)}$	€ $_{(2024)}$	kWh	c.€ $_{(2024)}$/kWh	c.€ $_{(2024)}$/kWh
3	9.000	40	3.600	12.600	83700	10,753	15,054
4	11.800	45	5.400	17.200	111600	10,573	15,412
5	12.300	50	7.500	19.800	139500	8,817	14,194
6	12.800	55	9.900	22.700	167400	7,646	13,560
10	17.200	60	18.000	35.200	279000	6,165	12,616
20	25.200	65	39.000	64.200	558000	4,516	11,505

Tab. 3

Naturally, this is a cost that decreases with the increase in plant power as shown in Fig. 5, which also provides a best-fit function for possible trend estimates according to plant capacity. But, unless it concerns small and medium-sized family businesses, it is difficult for a family to have a photovoltaic system with a power exceeding 20kWp for its own consumption. However, in this regard it must be said that local legislation limits the power for single-phase users to 6kW and this may constitute a limitation for families (not businesses) who, having single-phase systems, would like systems with power greater than 6kW.

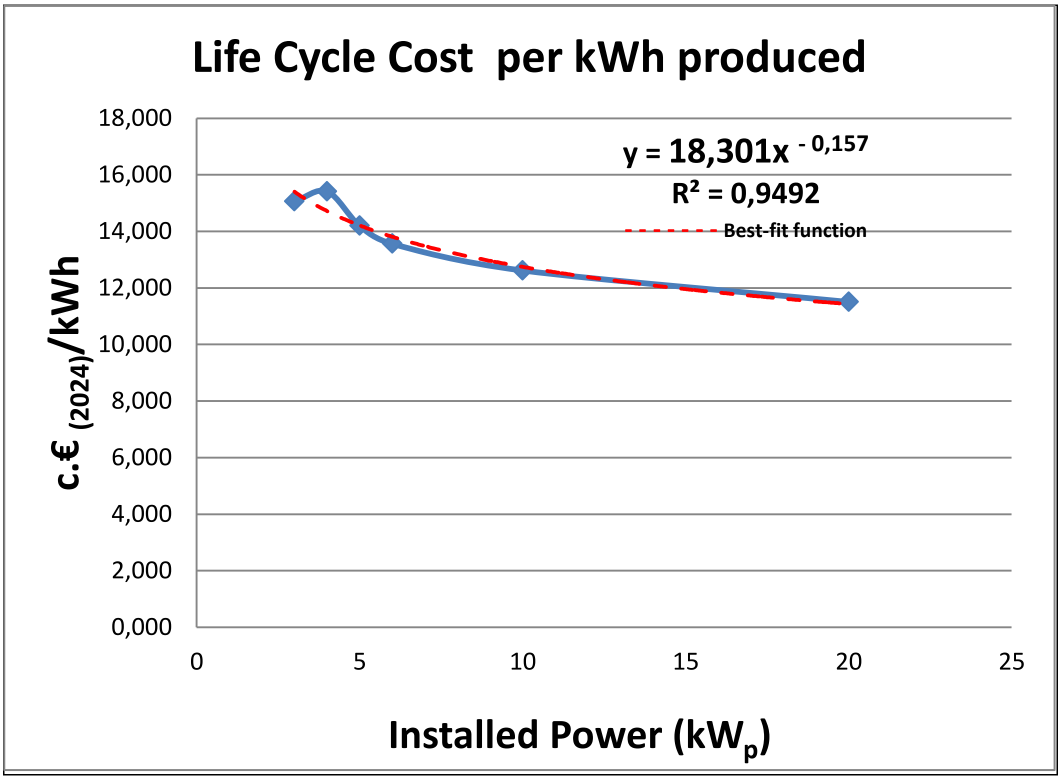


Fig.5

The current decreasing trend in the price of photovoltaic systems appears to favour the widespread market penetration of this technology, despite the upcoming climate changes and especially the hailstorms, which have recently caused considerable damage to systems of this type. Some sort of safeguard is starting to be necessary so as not to undermine families' investment in these essential technologies. Despite everything, photovoltaic electricity generation remains the technology of choice for distributed generation. Certainly not to carry out base load functions (usually carried out by fossil fuel or nuclear plants), and even less for network regulation functions, which were not ensured by other technologies (primarily hydroelectric) there would be no possibility of using extensive mode of wind and photovoltaic energy. The interconnection achieved by the European transmission and distribution networks is such that a disservice occurring in the

Balkans can have repercussions in the more industrialized regions of Italy, as demonstrated by recent research and facts.

It is illusory to think that through the imposition of a law in a Europe that is once again experiencing war, one can solve the energy problem of a country in crisis and trouble, with an archaeological real estate heritage and 10% of the population in absolute poverty, where the question that immediately arises is: who pays?. Furthermore, given the concentration that the existing wealth shows. The encouragement of photovoltaic expansion is beneficial not only for the environment, but also for energy independence and for reasons of energy security, but if it were imposed by law it would turn into bankruptcy, due to impossibility, non-compliance if not for open opposition from the citizens themselves. It should not be forgotten that many small plants contribute to the containment of CO_2 emissions and the concept of avoided CO_2 is now starting to circulate.

It can be assumed in a completely approximate way - taking into account indications from the Ministry of the Environment - that to produce one kWh of electricity, in the case of Italy, approximately 0.53 kg of CO_2/kWh is emitted. The EU-ETS prices - for Emission Trading associated with CO_2 emissions in the period January 2022 - March 2024 are shown in the following graph. These prices fluctuate between a minimum of 52 and a maximum of 100 €/t of CO_2.

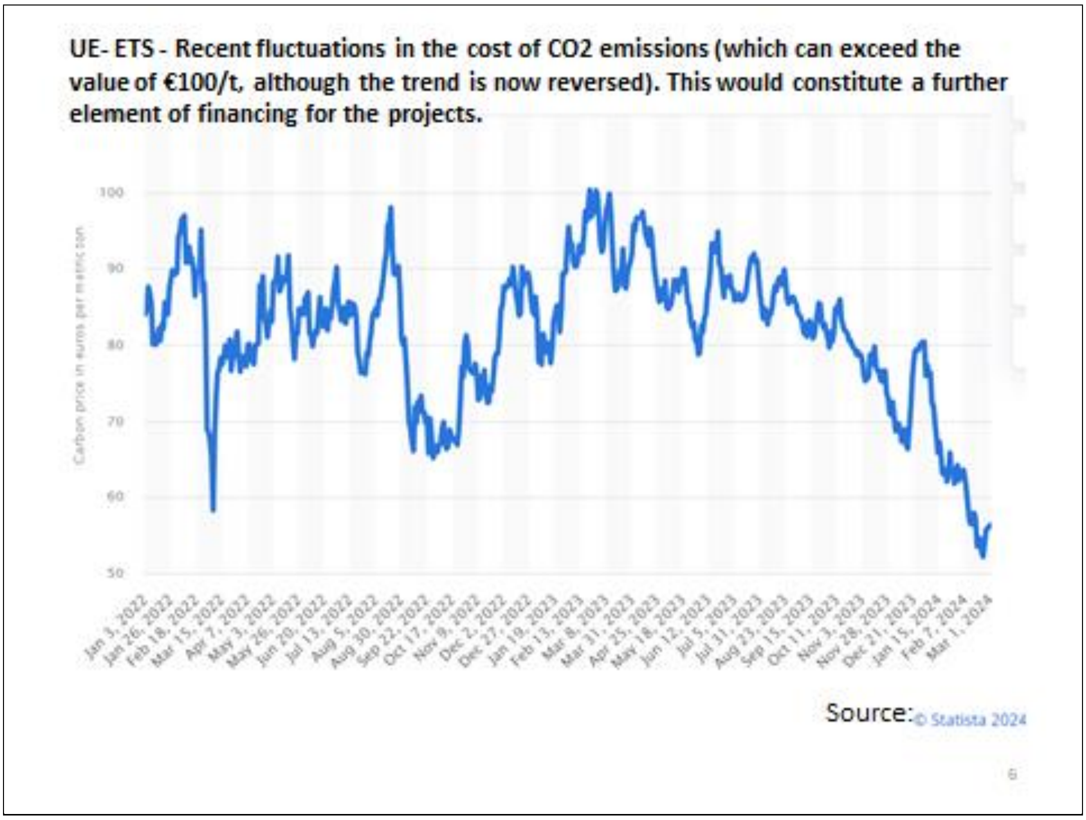


Fig.6

Based on this range of values, in Tab. 4 we wanted to carry out an exercise to assign a value to the CO_2 avoided by these small photovoltaic systems for family use over the course of their 30-year life cycle. It thus turns out that these "hypothetical" values could constitute significant quotas to repay the investment costs necessary for such small plants. A repayment over the life cycle, which would occur as the plant produces and the meters verify how much and how they produce.

It has always been difficult for the "proletariat" to understand the reasons of high finance and more concretely whether any idea is "bankable" or not! The adjective "bankable" scares rather than implies a

question! Indeed in this case it is perhaps difficult to say even if an idea or a question is implied here. But, certainly, before anything else, "up there" someone should say whether:
«According to European rules, can individual end users (e.g. families), equipped with photovoltaic systems for small-power electricity generation, issue and trade green certificates for the CO_2 avoided in proportion to the kWh produced?».[4]

Installed Power	Overall lifecycle production	Avoided CO_2 per kWh produced	Overall lifecycle CO_2 avoided	Overall Life Cycle Value in € of the CO_2 avoided according to the oscillation range in €/t of CO_2 for the purpose of the EU-ETS emissions trading system	
kW_p	kWh	kg of CO_2/kWh	t	Min = 52	Max = 100
3	83700	0,53	44,36	2306,77	4436,10
4	111600	0,53	59,15	3075,70	5914,80
5	139500	0,53	73,94	3844,62	7393,50
6	167400	0,53	88,72	4613,54	8872,20
10	279000	0,53	147,87	7689,24	14787,00
20	558000	0,53	295,74	15378,48	29574,00

Tab. 4

But at the same time someone should also have solved the "WHAT…..IF…" stabilizing the volatility of CO_2 prices, without which no type of project would be financeable any more than any risky game of chance.

In order to complete the general outlook a real case is provided hereinafter.

As an example, below is the planning with the related input/output data - (carried out with the simulator developed by Dr. M. Menichella, see www.consulente-energia.com) - for a 6kW family system which is under construction in the Rome area with panels that guarantee 22% efficiency, a 10-year general guarantee and an expected life cycle of 30 years.

FV-SIMULATOR 1.0

INPUT PARAMETERS		
Nominal electrical power of the system	6	kWp
Turnkey cost of the photovoltaic system	12800	€
Average annual producibility (see map)	1.200	kWh/kWp/ year
Average annual decay in producibility	0,4	%
Percentage of self-consumed energy	95	%
Electricity cost estimated from the bill	0,22	€ /kWh
Average value of energy delivered to the electr. grid	0,100	€ /kWh
Current tax deduction percentage		%
Duration of the loan in years	0	years
Monthly loan installment (see installment calculation)	0	€
Maintenance costs + Insurance	40	€ /kWp/ year
Estimated annual inflation rate	2,0	%
Increase in energy costs net of inflation	2,0	%
OUTPUT PARAMETERS		
Cost of the system per kW of power	2133	€
Electricity produced the 1st year of the system	7200	kWh
Electricity self-consumed by the Customer	6840	kWh/ year
Annual amount deductible from taxes	0	€
Income after 20 years - Investment case	18659	€
Income after 20 years - Financing case	31459	€

Tab. 5

[4] Energy communities of self-production and consumption are formed on the field and from below, because a relationship between humans and also a "business" is implicit in them. Building it by edict of the King can be done, but it requires the use of force and presumably "business" and "force" can be antithetical concepts for many.

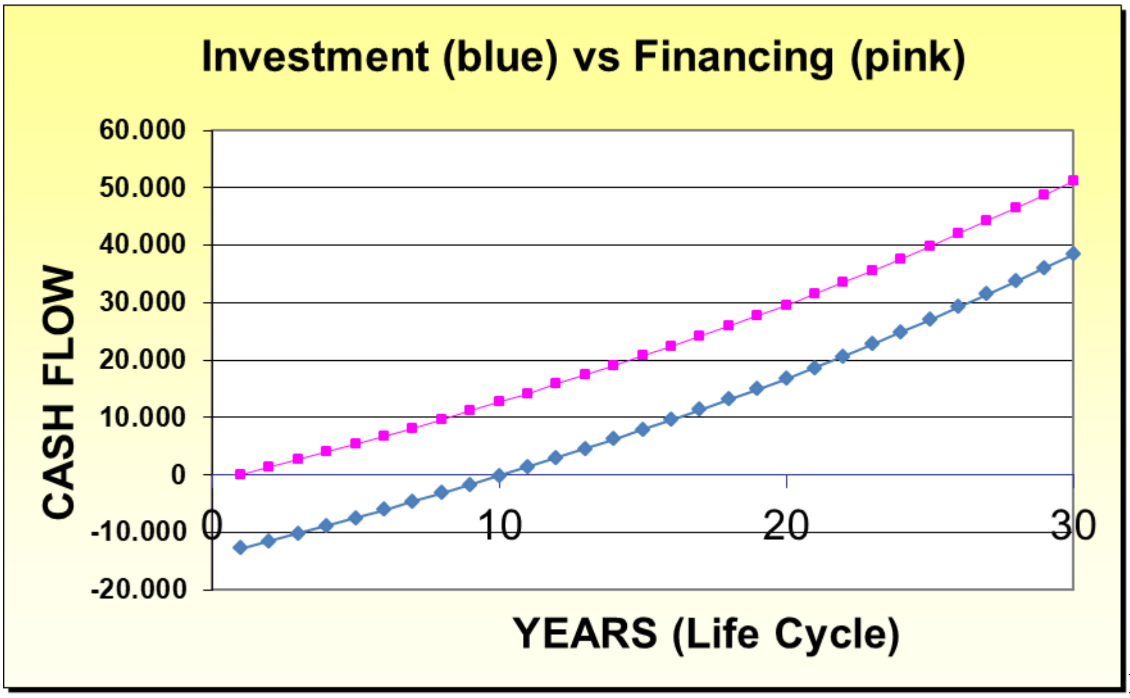


Fig.7

NOTE: As one can see, in the case reported above, the tax deduction was not taken into account, which is currently possible in the amount of 50% of the cost, "allocated by quota" over 10 years. If this tax deduction is taken into account, the cash flow graph changes as follows.

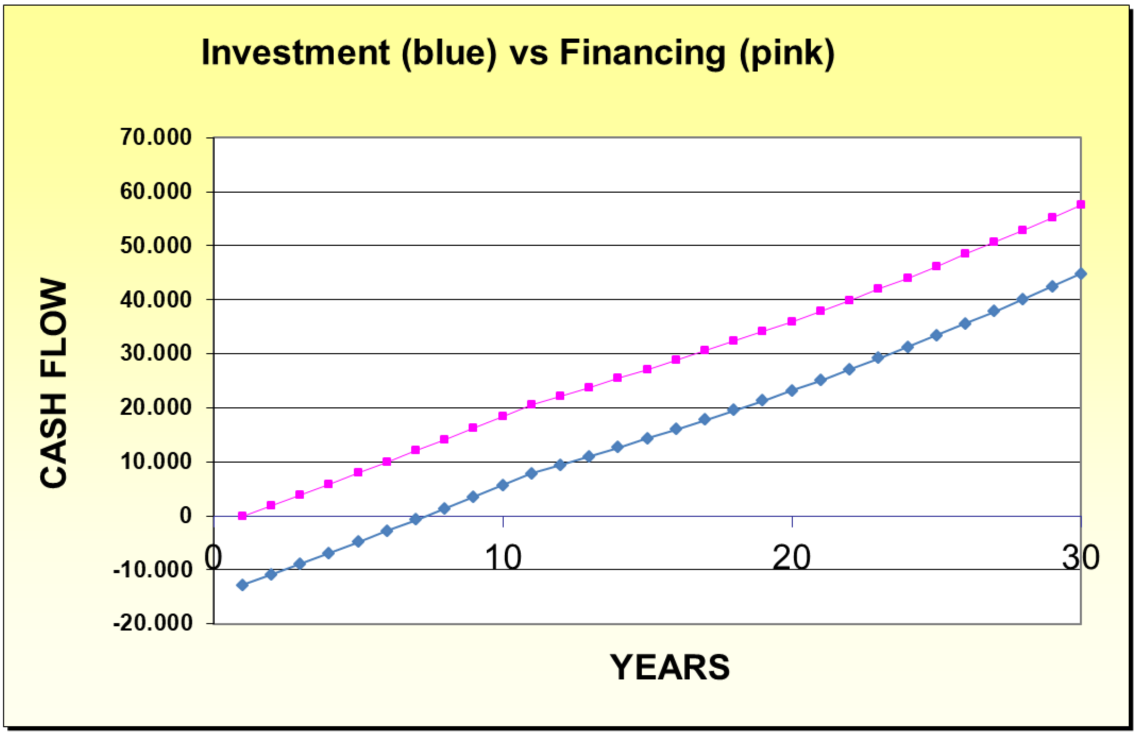


Fig. 8

To conclude, it seems appropriate to underline a final element of obstacle to the diffusion of small photovoltaic systems with a nominal power of 3 ÷ 4 kW, especially in small and large city condominiums. With the most recent technologies, these small photovoltaic systems require modest surfaces for their installation: for example. e.g. 15÷20 m2 and are very well suited to acting as covers (or screens) for balconies and terraces to replace the existing and already installed awnings, often absolutely necessary both in the hot summer seasons and in the rainy spring/autumn seasons, as well as in the winter ones. In short, the photovoltaic system can at the same time be a substitute for outdoor awnings, or coexist with them, especially in condominium homes; but this is hindered by both condominium and municipal (or regional) regulations which prohibit the alteration of the external "facies" of a condominium building. It is the belief of many that the removal of constraints imposed by similar regulations could greatly encourage the spread of small systems, which up to now have been effectively prohibited for the reasons set out above.

Rome, the 11th of May, 2024 / RMo