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A profitability assessment of small-scale photovoltaic systems in an electricity market without subsidies

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ABSTRACT

The installation of photovoltaic power plants in 2015 compared to 2014 registered a growth of 25.6%, reaching a cumulative power equal to 229 GW. In developed solar markets, as many European countries, the sector is pushed by the alignment between the electric power demanded and the one offered. Consequently, self-consumption makes consumers active players of the energy transition. Italy is evaluated as a case study in this paper, in fact is the first country in the world where solar energy contributes largely to the national energetic demand.

This paper aims to evaluate photovoltaic systems in residential sector without subsidies. Economic and environmental results are proposed and the indicators used are Net Present Value, Discounted Payback Time and Reduction in the Emissions of Carbon Dioxide. Three sizes (3 kW, 6 kW and 20 kW) are evaluated. In addition, a sensitivity analysis of critical variables (investment cost, annual electricity purchase price, annual electricity sales price, opportunity cost, tax deduction unitary, period of fiscal deduction, average annual insolation and percentage of energy self-consumption) demonstrates the robustness of the economic results. Also for environmental evaluation, alternative scenarios are proposed varying the value of emissions released by source energy analysed (photovoltaic, coal, oil and gas).

Economic and environmental results suggest that small-scale photovoltaic systems can support the transition towards a sustainable energy mix.

1. Introduction

The reduction of pollutant emissions and energy dependence on fossil fuels has driven many countries to encourage the use of renewable energy sources (RESs) with the aim to develop an economy with low carbon levels [1]. Sustainable development is a broad topic and the degradation of ecosystems is a complex challenge that requires responses based on environmental, economic and social impacts [2]. It is therefore appropriate to imagine urban areas integrated with RES installations, because in the future will be increasingly diffuse models of distributed generation characterized by increasing numbers of prosumers (consumers are also producers) [3].

The reliability and stability of electric systems is strongly influenced by the variability and non-dispatchable nature of RESs [4]. From one side conventional power system is centralized and typically transmit electricity over long distances, while from the other side Distributed Energy System (DES) is a decentralized more flexible technology located close to the load it serves [5]. Energy storage system (ESS) and demand side management (DSM) are two options for increased self-consumption [6].

A review on this topic has quantified the percentage increase of energy self-consumption: 10–24% with an ESS of 0.5–1 kW h per installed kW PV power and 2–15% with a DSM [7]. DES and ESS enable to collect energy from many resources representing an opportunity to reduce environmental impacts and improve supply security [8]. Moreover, a critical aspect is given by their costs that currently are very high [9]. The break-even point (BEP) of the increase of self-consumption at which residential photovoltaic (PV) battery systems become economically viable in a mature market is proposed by [10].

Distributed generation from RESs and penetration of renewables into the electric grid are playing a crucial role in the electricity energy market [11]. Smart grids could help to better integrate RESs with distribution and transmissions systems and they try to solve power's unbalances issues and other technical problems in real time [12]. Micro-grids are a specific portion of a smart grid and they operate in order to optimize energy fluxes [13]. A new

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Nomenclature

A_{cell}	active surface	K_f	optimum angle of tilt
BEP	breakeven point	LCA	life cycle analysis
bos	balance of system	N	lifetime PV system
C_{ae}	administrative and electrical connection cost	N_{debt}	period of loan
C_{inv}	total investment cost	N_{TaxD}	period of tax deduction
$C_{inv,unit}$	unitary investment cost	NPV	Net Present Value
C_{res}	residual capital	NREL	National Renewable Energy Laboratory
DCF	Discounted Cash Flow	η_{bos}	bos efficiency
dE_f	Decrease efficiency of system	η_f	number of PV modules to be installed
DES	Distributed energy system	η_m	module efficiency
DPBT	Discounted Payback Time	O	discounted cash outflows
DSM	demand side management	p^c	electricity purchase price
E_{cd}^{coal}	emissions released by a coal plant per unit of produced energy	p^{coal}	percentage of coal in energy mix
E_{cd}^{gas}	emissions released by a gas plant per unit of produced energy	p^{gas}	percentage of gas in energy mix
E_{cd}^{oil}	emissions released by an oil plant per unit of produced energy	p^{oil}	percentage of oil in energy mix
E_{cd}^{FF}	emissions released by fossil fuels per unit of produced energy	p^s	electricity sales price
E_{cd}^{PV}	emissions released by a photovoltaic plant per unit of produced energy	P_{Cass}	percentage of assurance cost
ER_{cd}	reduction of carbon dioxide emissions	P_{Ci}	percentage of inverter cost
E_{Out}	energy output of the system	P_{Cm}	percentage of maintenance cost
ESS	energy storage system	P_{Ctax}	percentage of taxes
FiT	feed-in Tariff	P_f	nominal power of a PV module
GHG	greenhouse gas	PV	photovoltaic
GSE	Gestore Servizi Energetici	r	opportunity cost of capital
I	discounted cash inflows	r_d	interest rate on loan
inf	rate of inflation	RES	renewable energy system
inf_{el}	rate of energy inflation	RPS	Renewable Portfolio Standard
IEA	International Energy Agency	t	time of cash flow
IPCC	International Panel on Climate Change	t_r	average annual insolation
		$TaxD_{unit}$	tax deduction unitary
		$\omega_{self,c}$	percentage of energy self-consumption
		ω_{sold}	percentage of the produced energy sold to the grid
		Vat	value added tax

methodology that resolve the problem of optimal electrical micro-grids design is proposed by [14] and furthermore, the development of an innovative device, which is based on a bidirectional converter, is analysed for the interface to the supply utility grid of combined RES based generators and ESS [15].

PV is a safe energy source, clean and competitive that can contribute to sustainable growth and plays a key role in the electricity global market [16]. In a starting stage of market the profitability of PV investments is determined by subsidies [17], while in a mature market this role is determined by the harmonization of consumption with the production [18]. A review of current grid codes in some countries with high PV penetrations and their management strategies are proposed by [19]. Policy choices can be oriented towards decreasing fossil fuel subsidies and tackle other barriers to RESs [20].

In such contexts, energy policy can be evaluated with appropriate quantitative analyses and the objectives of environmental protection and economic profit can coexist investing in PV systems [21]. This work is aimed at providing economic and environmental assessments to support future decisions concerning resource PV even in countries, where government subsidies are absent.

With this regard, the analysis is conducted taking as a case study Italy and evaluating specifically the residential sector, regarded as the locomotive of the future PV power installed in the world [22]. The conclusions of the work will be replicated for other national markets, since the nature of government incentives is "only" to support the development of the sector [23].

To sustain the obtained results it is proposed sensitivity analyses for both the economic and the environmental variables.

2. Materials and methods

The methodology used in this paper is based on several steps. This section proposes an overview of PV sector initially concerning the global context (Section 2.1) and then is analysed the Italian one (Section 2.2). Model assumptions and economic inputs are proposed in Section 2.3 and environmental inputs are defined in Section 2.4. Consequently, it is possible to define the aims of this paper:

- Results propose economic and environmental assessments in baseline scenario (Section 3).
- Sensitivity analysis (Section 4) and scenario analysis (Section 5) are applied to economic aspects in order to evaluate alternative scenarios.
- Sensitivity analysis (Section 6) is applied to environmental concerns in order to evaluate alternative scenarios.
- Policy implications are proposed in Section 7.
- Section 8 presents concluding remarks.

2.1. The global photovoltaic sector overview

The cumulative installed solar PV power capacity is equal to 229 GW in 2015. This value is very significant, compared to 41 GW in 2010. Europe accounts for the major global share at 97 GW but the Asia-Pacific countries have a similar value (96 GW) to the end of 2015. Finally America reaches 31 GW and Middle East/Africa only 3 GW [24]. 50.6 GW have been installed