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Environmental and economic analysis of building integrated photovoltaic systems in Italian regions

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ABSTRACT

Solar energy is a form of renewable energy that can be used to combat climate change through an environmentally accepted energy supply policy with support from both private and public consumers. There are numerous factors contributing to the definition of the economic and environmental performance of solar energy investments, such as average annual irradiation, consumers' consumption, Feed in Tariff incentive system, energy portfolio, emissions produced by the photovoltaic system, rated power of the individual modules, disposable income of the investor, availability of surface for the installation of the photovoltaic panels and *mission*, that characterise the project (environmental maximisation, economic maximisation or self-sufficiency of the system during the first year). Given the particular geographical position of Italy, the economic profitability and environmental impact of such system were estimated, first on the provincial scale and then on the regional scale, to delineate the general characteristics that are not caused by a single scenario. The indicators used include the following: net present value (NPV), internal rate of return (IRR), discounted payback period (DP_bP), discounted aggregate cost-benefit ratio (BC_r) and reduction of emissions of carbon dioxide (ER_{cd}). The ultimate objective of the paper is to define the number of photovoltaic (PV) systems necessary to reach the target of renewable energy production in the above settings. A general scenario appropriate to achieve this goal, as well as implementing the total wealth generated by this framework and the reduction of CO_2 emissions resulting from the implementation of that plan, will be examined. The indicators used are total net present value per capita and reduction of carbon dioxide emissions per capita.

1. Introduction

The economic crisis of 2008/2009 was the result of several factors related to the turbulence of financial markets, limited access to credit, rising unemployment and devaluation of assets. In this scenario, the development of energy resource prices, especially oil and gas, have underlined the problem of the limited resources against the high level of energy demand (Kenny et al., 2010; Shi et al., 2012; Dusonchet and Telaretti, 2010). In January 2009, the European Parliament approved the climate-energy package – the objective of the program is the achievement of the "20/20/20" targets by 2020: a 20% reduction in the emissions of greenhouse gases, with 20% energy savings and an increase of 20% in the use of renewable sources for energy production.

Accomplishing these grand challenges require the development of nations using the principles of a Green Economy, which involves having renewable energy supplies substitute for fossil fuel based energy supplies. The use of such renewable sources of energy is connected, moreover, to a greater level of efficiency from which they are derived to achieve further energy savings (Cucchiella and D'Adamo, 2012a, 2013; European Commission, 2011). To guide citizens towards energy conservation policies and a lower use of traditional energy sources, it is necessary to define an effective system of incentive policies that allow both the reduction or elimination of the cost of electricity bills and the generation of profits from the adoption of policies respectful of the environment (O'Driscoll and O'Donnell, 2013; Lüdeke-Freund and Loock, 2011; Toke, 2007).

This research is divided into several steps. First, the current state of the use of photovoltaic energy sources in the global landscape is analysed. This analysis focuses on the role Italy plays in this scenario. A critical literature analysis is presented that focuses on the absence

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of a certain aspect of PV evaluation model and describes the general characteristics of a photovoltaic system (Section 2).

In Section 3, the inputs necessary for the environmental and economic analyses are detailed, with special attention paid to the criteria used for the design of a PV plant. These criteria are defined considering not only the necessary power rating of the PV plant but also additional variables, such as the user financial resources available, the area on which to install the photovoltaic panels and the priorities to be achieved with the project (Singh, 2013; Zhang et al., 2013).

In Section 4, the technical, economic and environmental variables are presented, followed by two case studies (plants located in Milano and Palermo) that define the scaling of the PV system and the evaluation of the business plan.

In Section 5, moving from a provincial to a regional perspective, the business plan as a regional average of provincial analysis is evaluated. The indicators used are NPV, IRR, DP_bP, BC_r and ER_{cd}: these indicators were estimated three times because their values are linked to the criterion adopted.

Finally, Section 6 presents the multi-objectives scenario appropriate to achieving a renewable energy target, which will also determine the total profit generated by this framework (NPV per capita) and the amount of reduction of CO_2 emissions.

The concluding remarks of the paper are presented in Section 7.

2. The state of the art of photovoltaic technology

The EU has mandated the 20/20/20 target for renewable sources of energy. By comparing the share of renewable sources with the current International Energy Agency (IEA) projections, it is possible to indicate the strong differences between the several available renewable energy sources. According to the targets suggested by the 20/20/20 EU policy, the Wind, Biomass and PV industries each has an aggressive target to reach. These targets can be achieved through a combined implementation of all of the renewable sources of energy, including Hydro, Concentrated Solar Power (CSP), Geothermal and Ocean (Fig. 1).

At the worldwide level, there were 31.1 GW of PV systems installed in 2012, which represents an increase of 30.4 GW with respect to previous year. The production capacity of the PV systems installed in 2012 is at least 110 TWh of electricity per year, which is an energy level that can satisfy the annual power supply needs of over 30 million European households (Table 1).

The growth of the photovoltaic industry through incentive policies have helped make solar photovoltaic energy more affordable; however, the high costs of the initial investment that represent the main obstacle to the large-scale deployment of PV systems must be stressed (Cucchiella and D'Adamo, 2012a; Talavera et al., 2007), although, over the years, the cost of PV systems has fallen

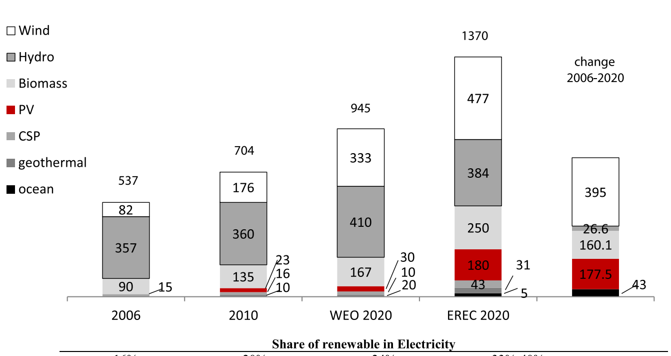

Fig. 1. Forecast of the contribution of renewable sources to electricity consumption (TWh (IEA, 2011)).

Table 1
World cumulative PV power installed in 2012 for primary countries.

	Market 2011 (MW)	Market 2012 (MW)	Cumulative 2012 (MW)	% Cumulative
Germany	7485	7604	32,411	31.7
Italy	9454	3483	16,361	16.0
China	2500	5000	8300	8.1
USA	1867	3346	7777	7.6
Japan	1296	2000	6914	6.8
Spain	472	276	5166	5.1
France	1756	1079	4003	3.9
Belgium	996	599	2650	2.6
Australia	837	1000	2412	2.4
Czech Republic	6	113	2072	2.0
United Kingdom	813	925	1829	1.8
Total	30,391	31,095	102,156	100.0

according to a learning rate estimated to be between 15% and 20% per year (Koroneos and Tsarouhis, 2012; Raugei and Frankl, 2009).

In the scientific literature on PV systems, many papers focus on the advances in this rapidly developing technology. The more relevant factors affecting the operation and efficiency of a PV system are: PV cell technology (monocrystalline, multicrystalline, thin-film, multi-junction, concentrating), environmental conditions (irradiance, temperature, dirt/dust) and selected equipment (batteries, chargers, power electronic devices and wiring) (Meral and Dinçer, 2011). The optimum energy yield is achieved using thin film PV modules, whereas the best environmental results are achieved using crystalline PV cells (Cucchiella and D'Adamo, 2012b).

In remote areas, where there are necessarily low/medium power levels, PV systems are the optimal choice due to the easy scaling of the input power source. However, compared with conventional energy supplied by means of the current grid supply, the price of an energy unit generated from a PV system is higher (Singh, 2013). Some authors underline the relevance of the method used for evaluating the reliability of large-scale PV systems and the techniques for quantifying the effects of PV interconnection on distribution system (Zhang et al., 2013). New manufacturing technologies, building integrated photovoltaic products (BIPV) and the application of PV-thermal will further increase the environmental performance of PV systems (Peng et al., 2013). Many BIPV systems offer good weather tightness, satisfactory appearance and fairly high conversion efficiencies. New technologies (organic based PV, such as dye sensitised TiO_2 cells) promise shorter energy and economical payback times (Petter Jelle et al., 2012).

The sustainable management framework defined in this paper has drawn on previous analyses related to:

- The definition of indices for the estimation of the energy and environmental performances for a BIPV system, specifically energy payback time (EPBT), greenhouse gas per kilowatt hour (GHG/kWh), Energy Return on Investment (EROI), greenhouse gas payback time (GPBT) and greenhouse gas return on investment (GROI) – Table 2 – (Cucchiella and D'Adamo, 2012b);
- The definition of indices for the estimation of the economic performances for a BIPV system, specifically Net Present Value, Internal Rate of Return, Discounted Payback Period, Discounted Aggregate Cost-Benefit Ratio and Reduction of the Emissions of Carbon Dioxide (Cucchiella et al., 2012a);
- The definition of the investment characteristics that can support the investor during the decision making process, specifically opportunity cost of capital, project lifetime, plant size, geographical location of system, Feed in Tariff, investment cost, annual energy output and electric energy required (Cucchiella and D'Adamo, 2012a);

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