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End-of-Life of used photovoltaic modules: A financial analysis

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ABSTRACT

The photovoltaic (PV) industry has a relevant role in terms of energy systems sustainability. The economic and environmental benefits related to its application brought the PV sector to an overall installed power of about 138 GW in 2013 (+24% compared to 2012).

The recent update of the European Waste Electrical and Electronic Equipment (WEEE) Directive classifies End-of-Life (EoL) PV panels as an electrical/electronic waste. Hence, it became mandatory to define alternative strategies to landfill [1]. The scientific literature presents different interesting technological solutions, together with related environmental benefits coming from the PV modules recycling. However, there is a clear fragmentation from an economic point of view [2].

The aim of this paper is to apply a financial methodology, like the Discounted Cash Flow (DCF) analysis, for the assessment of PV modules recycling process profitability. This method goes to evaluate two main indexes, as the Net Present Value (NPV) and the Discounted Payback Period (DPBT). The Italian context is selected as a reference case study for the definition of an optimal plant capacity size related to current and expected national market volumes. To this aim, two types (pilot and industrial) of plants are proposed by the authors. The obtained financial results are useful to support future strategic decisions about the PV recycling management.

Contents

1. Introduction

PV power is currently one of the fastest growing power-generation technologies in the world, mainly driven by technological improvements that reduced costs, and government policies supporting renewable energy sources [3,4]. At the end of 2013, the cumulative PV

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Nomenclature

AC_l :	avoided cost of landfill
C_c :	total collection cost
C_c^u :	unitary collection cost
C_{cm} :	total conferred material cost
C_d:	total debt cost
C_e:	total shareholder's equity cost
C_{inv}:	total investment cost
C_{inv}^u :	unitary investment cost
C_{lcs}:	loan capital share cost
C_{lis}:	loan interest share cost
C_{ocm} :	unitary other conferred material cost
C_p :	total process cost
C_p^u :	unitary process cost
C_t:	discounted cash flow
C_{tax}:	taxes cost
C_w :	total waste cost
DPBT:	discounted payback period
Ebt:	earnings before taxes
Ebit:	earnings before interests and taxes
$f_{w,t}$:	waste fee
I_t:	discounted cash inflows
inf:	rate of inflation
m_m^m :	mass/module of conferred material
m_{rm}^m :	mass/module of recycled material
m_w^m :	mass/module of waste
N:	lifetime of investment
N_{debt}:	period of loan
NPV:	net present value
O_t:	discounted cash outflows
ocm:	other conferred material
p_{rm} :	purity level of recycled material
R_{rm} :	revenue of recycled material
r_d:	interest rate on loan
r_e:	opportunity cost
rm:	recycled material
S:	plant size
t:	time of the cash flow
t_f:	tax rate
WACC:	weighted average cost of capital
ω_d :	debt percentage
ω_e :	equity percentage
y_{rm} :	yield of recycled material

capacity around the world reached more than 138 GW. Over the past four years, 83% of the overall available power has been installed [5].

A financial analysis of the renewable energy sector has demonstrated that investments have reliable and healthy long-term financial returns with low levels of risk [6,7]. There are numerous factors contributing to the definition of the economic performance of renewable energy investments, such as subsidies, sale price of energy, investment cost, equivalent operating hours and the size of the plants. PV technologies can reach the aim to decarbonize the power generation system [8] and a literature review has highlighted that one of the greatest challenge of the PV system is its cost effectiveness [9]. The incentive scheme has encouraged and accelerated the deployment of energy produced from PV sources in several countries and it represents the preferable tool in new markets [10]. Instead, in absence of support mechanisms, the harmonization of the consumption and production of electricity (self-consumption) determines the profitability of PV facilities [11]. Furthermore it is opportune highlighted that the combination between solar systems, heat pumps and heat use can add additional profits and can reduce environmental pollution. Several papers have shown that the heat pump offers economic advantages [12–14].

With the growing installation of PV systems and limited availability of resources, the End-of-Life (EoL) management of these products is becoming very urgent [2]. In fact, these scraps represent a potential source of environmental pollution because they can contain hazardous materials, such as Pb, Cd, Cr and Bi, that cause serious illnesses in humans because of their toxicity [15,16]. Furthermore, the expected volumes estimated by some experts (e.g. [17] speak about 50,000 ton of scrap PV panels generated all over the world since 2015) give some idea of the issue.

The recent decision taken by the EU commission to include PV panels into the new WEEE directive follows these expectations, trying to limit in some way the negative impacts. In fact, being now PV panels a WEEE category, implicitly imposes the Extended Producer Responsibility (EPR) principle also to PV panel manufacturers. Basing on this principle, they have to ensure the right collection and recovery of EoL products within European borders. In the United States the Environmental Protection Agency has regulated EoL disposal of solar products under the Federal Resource Conservation and Recovery Act (RCRA). However, issues about the management of scrap PV panels goes to be added to the more general issue about the management of WEEEs.

Globally, about 30–50 million tons of WEEEs are disposed each year and the estimated annual growth rate is equal to 3–5% [18]. For example, Asian and EU countries together dispose an estimated amount of 12 and 6.5 million tons/year of WEEE, respectively [19]. These numbers makes the management of WEEEs an interesting challenge toward sustainability [20] and its positive impact on GHG mitigation was already analyzed by the literature [21] also in terms of Sustainable Supply Chain Management (SSCM) [22].

From an environmental side, even if the sustainability of PV panels in terms of decommissioning, disposal or energy requirements is well-stressed by the literature, these analyses are underestimated, by negatively influencing also the related energy and emissions analyses based on Energy Payback Time (EPBT) and Greenhouse Gas Payback Time (GPBT) indicators [23]. For example, in Italy EPBT and GPBT are equal to 1.8–2.9 years and 2.5–3.3 years, respectively [24]. However these dates could be decreased by about 1.7% if recycling would be considered in the analysis [25].

From the technological side, previous works suggested that the recycling of silicon based and thin-film PVs is technically possible [26,27]. Unfortunately, they are not yet fully implemented because of the current lack of collection networks in many countries (e.g. Europe implemented a dedicated infrastructure only in 2007). However, thanks to new governmental, economic, environmental and human health policies, this trend seems to begin its inversion [28].

Finally, from the economic side, what emerges from the literature is that the profitability of investments related to the construction of PV recycling facilities seems to be guaranteed only by the management of great amounts of wastes. The authors decided to analyse the Italian context with the aim to assess if the presence of current low volumes and the expectation of great volumes in the next future can support (or not) the development of a national PV panels recycling chain.

The paper is organized as follows: Section 2 presents a literature analysis about PV panels recycling with a technological, environmental and economic perspective. Section 3 focuses on the Italian market, by calculating the amount of wastes to be recovered under a high uncertainty. This way, it is possible to define the number of plants to be constructed in function of the selected optimal size. Section 4 presents an economic model developed and used to evaluate four case