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A methodology to identify potential markets for small-scale solar thermal power generators

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HIGHLIGHTS

- Innovative approach to inverse market assessment of small CSP–STE systems.
- New figure of merit assessing social, technical, economic and political factors.
- Risk management included according to usual practice in other sectors.
- Probabilistic approach to uncertainty analysis.
- Methodology easily tailored to virtually any technology and business case.

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ABSTRACT

This paper presents an innovative methodology to perform market analysis of a new solar power generation technology based on parabolic dish and micro gas turbine engines. Technical, economic, social and political parameters of influence are combined together into a single figure of merit: *index of market potential*. This index is an original approach enabling the identification of the potential markets for this technology, tackling the inverse problem (from technology to market identification) in lieu of the usual direct problem (determining the interest of a technology in a predefined region).

The paper takes into account the availability of solar energy, population distribution, intensity of the electricity consumption, economic indicators, business environment and legal framework for a set of more than twenty countries. Risk assessment tools at various levels are also built into the numerical tool, which is not the case in similar works reviewed by the authors.

Finally, the methodology includes a probabilistic approach to handling uncertainty in the input data. The result of this confirms that the methodology is robust and is not very affected by changes in the initial assumptions.

1. Introduction

Renewable energies play a major role in today's energy market due to the combination of fossil fuel price/reserves, increasing electricity demand and environmental concern [1]. These are the main factors that have contributed to the widespread utilisation of the formerly unconventional sources, amongst which large scale Solar Thermal (STE) power plants are found. These are now a consolidated technology with a total installed capacity over 4 GWe worldwide at the end of 2013 and forecasts for more than 250 GWe by 2030 [2]. Starting from the 10 MWe solar tower in Spain and growing to 50 MWe initially for parabolic trough technology, the industry is now seeing projects with over 150 MWe in single power block configuration. The root cause for this trend is the agreement that the technology holds significant economies of scale [3]. The downside is nevertheless the numerous hurdles that small scale solar thermal power systems have encountered to enter a market where they have to compete against the low cost, ease of operation and reliability of photovoltaic technology. Such is the case of Stirling dish technology whereby a parabolic dish collector concentrates energy onto a reciprocating engine which in turn produces electric power. The high cost of the dish and engine, the similarly high operating and maintenance costs of the latter running at almost 200 bar pressure with hydrogen in it, and the low technol-

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Nomenclature

ρ_{pop}	population density	f_{import}	imported electricity sub-factor
A	access to electricity	F_I	irradiance factor
c	per capita consumption of electricity	f_{policy}	regulatory framework sub-factor
F_ρ	dislocation factor	F_P	energy policy factor
F_D	demand factor	$f_{renewable}$	renewable energy share sub-factor
F_F	financial risk factor	f_{wealth}	microeconomic wealth sub-factor
f_{growth}	macroeconomic wealth sub-factor	P	population
F_G	grid factor	S	public expenditures

ogy manufacturing level add up to a final cost of electricity exceeding 0.30–0.35 USD/kWh [2].

In this scenario, a group of European companies and research centres have formed a consortium to investigate whether or not the parabolic dish collector technology is inherently more expensive than photovoltaic (from a consumer's perspective) or if, on the contrary, utilising a micro gas turbine in the range from 5 to 25 kWe can become techno-economicaly competitive in the small scale solar power generation market. More information about the Optimised Microturbine Solar Power system (OMSoP) project is available in [4]. To answer this question, the work is organised as follows:

- The first step is to characterise the potential scenarios where this technology is likely to be deployed successfully. This will allow to set accurate boundary conditions of a subsequent techno-economic analysis from which the lowest cost of electricity possible will be obtained.
- The second step is to perform a cost analysis of the system in order to estimate the capital, installation, operation and maintenance costs as accurately as possible.
- The third step is to perform system appraisal for a number of applications/customers within the identified markets.
- The last step is to integrate the previous tasks into an optimiser in order to obtain the most cost-effective design.

2. Aim and scope of work

Market analysis is a mandatory first step in the process of developing a product aimed at worldwide commercialisation. There are many examples of this in literature and power generation systems are not an exception to it, in particular those that are more innovative and bring about more uncertainty into the investment decision: organic Rankine cycles [5], fuel cells [6], concentrated solar thermal electricity [7] and, to a lesser extent, wind power [8].

Table 1 presents a comparative analysis of the features that are typically considered when assessing the market potential of competing technologies. It is to note that, in addition to the common economic, technical and environmental aspects, the table adds a fundamental feature that is usually overlooked: *risk*. According to Fraser, risk was introduced by the liberalisation of the power generation market and its nature (the "risk profile") is different for different types of generation technology and fuels [9]. Such differences are made even more evident in Table 2, where the differential features between conventional and renewable energy projects are summarised [10]. In the light of Tables 1 and 2, it is concluded that risk management is crucial in the appraisal of energy projects and, even if there are commonalities between conventional and renewable energy technologies, this task is project specific. New methodologies are hence needed when considering new technologies.

Further to the considerations above, most market analyses for power generation technologies available in literature limit to the application of one technology in a particular country or region [11–21]. This makes it a direct problem wherein the location is defined *a priori* and the suitability of a reference technology in that particular region is evaluated. The approach presented in this work is different though since a technology is considered and the countries where it could be successfully deployed are identified (inverse problem), not only qualitatively but also quantitatively.

For the sake of clarity, the innovative features of this work are listed below:

- To the authors' best knowledge, even if there are market analyses of the direct type for other power generation technologies [22–25], there are no studies available for dish-mGT systems. It is true that some thermodynamic [26–28] and even techno-economic assessments [29–31] have recently been made available in the public domain both for stand-alone [29,31] and multiple units [30], but these are just general economic assessments with generic assumptions that are not representative of a particular market. Rather, they merely evaluate the thermodynamic potential of the technology and provide an estimate of the installation and production costs.
  Thus, the work presented in this article provides the reader with a novel tool to evaluate if and where this technology is bond to penetrate the market first.
- The tool does not rely on evaluating the costs of the technology in a deterministic manner. On the contrary, it is based on a *GIS* (Geographic Information Systems) approach whereby various features are rendered in layers (with spatial resolution) and then combined altogether according to certain integration criteria. Even if this is not new to market analysis [24,32–36], it is the first time it is used for a dish-mGT system.
- The methodology developed for market analysis considers the smart integration of a very wide group of features, both horizontal and vertical-wise. This includes:
  - Parameters of a very different nature: technical, economic, social, financial, and political. It is worth noting that even if some of these have already been used in similar studies, the authors are not aware of a previous integration of all these features into a single figure of merit. The risk-related financial features are very relevant in this regard [9].
  - Horizontal integration, meaning the integration of parameters of the country that are very different in nature: population density, consumption nodes and solar resource for instance.
  - Vertical integration, meaning the integration of micro-scale (population density) and macro-scale (electricity imports, GDP) properties.
- Two different layouts are considered simultaneously: stand-alone systems and large arrangements with lots of units. Most works available in literature focus either on stand-alone applications [32,37] or farm arrangements [30,38] but not both at the same time.