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Cost analysis of solar thermal power generators based on parabolic dish and micro gas turbine: Manufacturing, transportation and installation

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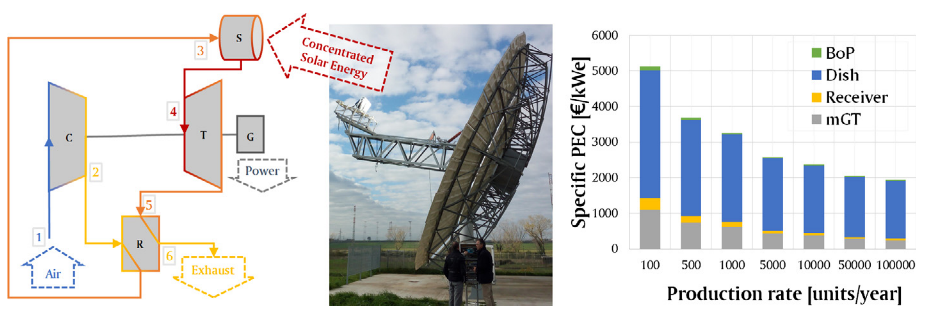
HIGHLIGHTS

- Cost analysis based on data provided by original equipment manufacturers.
- Manufacturing, transportation and installation costs are considered.
- Installation cost is 3250/3300 €/kW$_e$ for solar-only/hybrid stand-alone systems.
- Potential for 25–40% cost reduction if the system is mass-produced.
- Upgraded system capable of achieving 2550 €/kW$_e$ installed cost.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents a detailed cost analysis of a small-scale Concentrated Solar Power (CSP) generator based on parabolic dish collectors and Micro Gas Turbines (mGT), whose technical feasibility was already demonstrated in previous publications by the consortium. The system can be used for either electric power or combined heat and power generation, whether operating on solar energy only or with fossil fuel backup. Accounting for manufacturing, transportation and erection costs, and with manufacturing cost functions sensitive to system size and production volume, a single-shaft recuperated engine with different technological levels (low and high performance specifications) is considered. The results show that the specific cost of the base-case low performance system (1000 units/year) is slightly lower than 3300 €/kW$_e$ but can be reduced by 27.3% if the annual production rate is multiplied by ten, or 40.4% if it is multiplied by a thousand. This cost is lower than that of dish-Stirling systems but higher than for photovoltaic panels, even if at very high production volumes. Furthermore, the utilisation of high performance specifications reduces the cost of the system to 2500 €/kW$_e$ thanks to a substantial reduction of the size of the dish. At this cost level, the system has the potential to become competitive against photovoltaics under favourable environmental, political and market conditions.

1. Introduction

The OMSoP project, *Optimised Microturbine Solar Power Generator*, funded by the European Commission through the 7th Framework Programme is the most recent attempt to develop a cost-effective small-scale generator of solar electricity that can compete effectively against PV technology [1]. The challenge is large indeed, given the numerous projects that were carried out in the past with unsuccessful results, either using Stirling engines [2,3] or mGTs [4,5], but the consortium is confident to deliver a cost-competitive system thanks to a totally new design from scratch (rather than an adaption of existing components). A

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Nomenclature

C_{BoP}	balance of plant cost	*Man*	manufacturing
C_{Dish}	dish collector	mGT	Micro Gas Turbine
$C_{Installed}$	total installed cost	PM	profit margin
C_{Ins}	installation cost	*Rcv*	solar receiver
C_{PEC}	major purchased equipment cost	SR	Simple Recuperative
C_{Tr}	transportation cost		

thorough review of the past work in dish-based systems is provided in [6] by Semprini et al. and will not be repeated here except for the citation of the most relevant works.

The approach to dish-based technologies has been mostly technical in the past, with a large number of works trying to devise the smartest integration layout and simulating the expected performance under various operating conditions: available solar resource, ambient temperature and operating strategy (hybridisation) amongst others. Some examples of these are given by Laumert and co-workers [7–11], Le Roux and co-workers [12–17] and in other references like [1,18–21]. Regarding the economics of the system, the extensive work developed under coordination of the Joint Propulsion Laboratory (JPL) and the Department of Energy in United States (DOE) is worth noting [22–25]. More recently, a preliminary market assessment has also been provided by Sánchez et al. in [26] whilst other mixed techno-economic evaluations of OMSoP and OMSoP-related systems can be found in [9,10,27–29].

In general, the following flaws are identified in the cited previous works in the topic:

1. Lack of updated manufacturing costs of dish-based mGT systems, either globally or independently for its main equipment. This is particularly noteworthy for the cavity receiver as this is a new design specific to the OMSoP project and hence no economic information has been provided in literature before. For the microturbine, some cost functions have recently been presented in literature but without accounting for the impact of economies of scale [29].
2. Oversimplification of the economic analysis, which is typically based on general reference costs that do not account for aspects such as production volumes, technical specifications or hybridisation.
3. Lack of optimisation.

To tackle these weaknesses, the present work provides an assessment of the manufacturing, transportation and installation costs, based on real figures given by the consortium members and not on mere estimates or rough numbers. The manufacturing costs provided in the paper are also sensitive to the technical specifications (technological level) and production rate so as to enable a complete optimisation of the system (interestingly, the information provided by JPL in the 1980s included a dependence upon production volume but not technical specifications). The exploration of cost-competitive solutions is therefore wider in this work as it incorporates the possibility to estimate the cost of the hybrid system (unlike previous works in the topic). Another interesting feature is that system costs are broken down into the main constituents individually: mGT, receiver, dish and Balance of Plant (BoP) equipment.

With this in mind, the aim of the present work is summarised by the following bullet points:

1. To identify the main drivers of the individual and global manufacturing costs and their impact on the system specific cost, including potential economies of scale.
2. To provide a reliable and meaningful tool to help reduce system costs through optimisation, with the long term objective to make this technology competitive against photovoltaic and dish-Stirling systems.
3. To identify the optimum configuration and size, yielding minimum specific cost.

The work is structured as follows. A brief introduction summarising the main features of the system -layout, working cycle and specifications- is followed by a thorough discussion of the main costs of the system components. This discussion includes data provided by the consortium of the OMSoP project and a comparison against the little information found in literature. The resulting Purchased Equipment Cost (PEC) is then complemented with transportation and installation costs for the same potential locations considered in [26], yielding the final installation costs. Finally, a comparison is presented against competing technologies, either solar thermal (dish-Stirling) or photovoltaic.

2. Cost analysis in project engineering

The technical and economic appraisal of energy projects is founded on cost estimation and performance analysis, information that is then integrated following procedures dependent upon the project objectives. Accordingly, the methodologies for technical cost analysis found in literature are inherently heterogeneous and case-specific [30–37]. Amongst these, Bejan et al. [36] and Boehm [37] develop spreadsheet based calculations that can be adapted to a general cost analysis of thermal systems.

The most important stages to integrate in the engineering design process are: generation of alternative preliminary designs, synthesis (i.e., practical implementation of the concept), analysis and, finally, optimisation. The analysis of the actual system is usually the lengthiest phase as it involves technical work (evaluating the size of the system and its thermo-mechanical performance) but also less technical activities like assessing the reliability of the system and its compliance with safety measurements. Calculating/estimating the actual costs of manufacturing, assembly, transportation and installation is also of paramount importance in this phase. Finally, the optimisation process relies on the methodologies set in the synthesis and analysis stages which are combined to yield the optimal solution according to the design objectives.

Focusing on cost analysis, the first mandatory step is estimating the capital investment cost. This is actually of uttermost importance in the case of solar thermal power generators which typically exhibit low operational costs (available solar energy in the environment is “free”) and very high capital costs (solar energy collection system).

A useful cost estimating methodology that is specific to Research & Development projects is provided by NASA in [34]. It involves twelve steps that are organised in the following three main tasks, as illustrated in Fig. 1: