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Parametric study of the operational and economic feasibility of Stirling micro-cogeneration devices in Spain

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HIGHLIGHTS

- Techno-economic viability of Stirling μ CHP in detached houses in Spain is analyzed.
- Installations are simulated using dynamic simulation software during a year.
- Stirling micro-CHP devices are not economically feasible in Spanish detached houses.
- Decreasing investment costs could make these devices feasible in the coldest zones.

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ABSTRACT

This paper analyses the operational and economic viability of Stirling engine-run micro-cogeneration units in single-family houses in Spain. Thermal demands for the reference dwelling, sited in three different and representative climatic zones, are obtained based on heating and domestic hot water requirements. By carrying out dynamic simulations of both the conventional and cogeneration installations, their performances are obtained and compared. Additionally, based on the results obtained in the simulations, economic viability of the Stirling engine-based micro-CHP is evaluated, taking into account Spanish regulation and economic framework, particularly fuel and electricity prices.

Finally, a sensibility study is carried out in order to evaluate how economic results of these plants are affected by both variations in fuel and electricity prices as well as in initial investment costs.

It is concluded that there is no opportunity for these devices to be feasible in new and retrofitted single-family dwellings sited in any climatic zone of Spain but in the coldest ones, where the micro-CHP plants could become viable if the Stirling engine investment cost decreases.

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1. Introduction

Nowadays all countries are developing sustainable energy policies to reduce energy consumption in buildings, and to produce that required amount of energy in a more efficient way. Thus, technologies such as micro-cogeneration, which has been developed and promoted during the last years, become an attractive alternative to conventional energy plants for fulfilling energy demands in residential buildings, as they feature many environmental, functional and economic advantages [1–3].

Stirling engine-based micro-CHP devices are becoming a widespread solution for supplying heating, domestic hot water (DHW) and electric power in dwellings, as they feature not only the

advantages of CHP but also the benefits of Stirling technology, such as carbon dioxide low emissions, low noise and vibration-free operation, and multi-fuel capability [4,5]. Such devices are mainly designed to be used in single-family houses, so that most part of thermal and electric demands can be covered. As mentioned by Van Bael et al. [6], many field tests and research projects executed in several countries reveal that this technology provides potential benefits in domestic using. Ren and Gao [7] affirm that currently five countries – Japan, Germany, United Kingdom, Netherlands and United States – are the most actively involved in researching and introducing these gas-fired systems in the market. In this sense, Kuhn et al. collect in Ref. [2] results of field tests carried out with different Stirling micro-cogeneration devices in various regions of Germany, as well as in other countries such as United Kingdom, France and the Netherlands, reaching satisfactory results for small-scale applications.

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Nomenclature			
C_F	cost of the natural gas consumption (€)	$RefH_\eta$	harmonized efficiency reference value for separate production of heat
C_M	cost of operation and maintenance (€)	t	year of operation of the plant
E	electricity produced by the cogeneration unit (kWh)	Abbreviations	
F	natural gas used by the cogeneration unit (kWh)	CS	climatic severity
H	heat produced by the cogeneration unit (kWh)	CTE	Technical Building Code
i	annual hour	DHW	domestic hot water
I_{AC}	cost of the natural gas avoided consumption (€)	ECBCS	Energy Conservation in Buildings and Community Systems Program
I_E	avoided costs owed to sales and self-consumption of the electricity generated in the μ CHP (€)	GHG	greenhouse gas
Inv	total investment (€)	GWP	global warming potential
LT	lifetime (years)	IDAE	Institute for Energy Diversification and Saving
NPV	net present value (€)	IEA	International Energy Agency
NS	annual net savings (€)	LCA	life cycle assessment
PES	primary energy saving	LCI	life cycle inventory
r	ratio of discount	RD	Royal Decree
$RefE_\eta$	harmonized efficiency reference value for separate production of electricity	μ CHP	micro combined heat and power

Alanne et al. [8] carried out a simulation-based techno-economic assessment of a Stirling micro-CHP device installed in a single-family house located in Finland, achieving 3–5% decrease in primary energy consumption and CO₂ emissions compared to a traditional heating system, and obtaining substantial economic savings. More recently, Magri et al. [9] developed an economic and energetic performance analysis of a Stirling engine with an electric output of 1 kW, installed in a detached house in Italy. Results show that installing the studied system leads to reducing primary energy consumption and greenhouse gas emissions, as well as obtaining economic benefits. In the case of Spain, no significant research has been developed in this area, so the building-integrated performance of this technology is rather unknown.

Despite the satisfactory results obtained through the researches carried out, there are still many market entrance barriers, and this kind of equipment is only commercially available in a few countries all over the world.

There are several Stirling engines developed in a wide range of power capacities. Free piston Stirling engines cover an approximate electric power range of 1–25 kW, representing a suitable technology for small micro-cogeneration applications [1]. Nowadays, there are some commercially available Stirling engine-based μ CHP systems, such as Ecogen™ and eVita™ of BDR Thermea® or Whispergen EU1™ by WhisperTech® [10], being the most spread and characterized one the latter. This unit is based on a four cylinder alpha kinematic engine. Detailed information about the Stirling cycle and its configurations can be found in Ref. [11].

In this paper, a study that constitutes a first step in estimating the techno-economic potential of the Stirling engine-run micro-CHP devices is developed for residential buildings in Spain, approaching the case of new constructed and retrofitted detached houses. The work aims to provide a global view of the performance and economic results this technology can achieve in a Spanish generic single-family dwelling, distinguishing among different representative climatic zones, and considering both present and possible future economic and regulatory conditions.

This article is organized in five main different sections, as follows: Section 2 provides an overview of the current normative and economic framework for cogeneration in Spain. Section 3 provides a description of the characteristics of the building and its use and the climatic conditions the building has to withstand and the consequent obtained demand profiles it has to cover. It also includes the

definition of the designed micro-CHP and conventional plants for supplying the estimated energy demand in terms of heating and DHW, and a brief mention of the simulation procedure. Likewise, performance and economic basis used to analyze the viability of Stirling micro-cogeneration devices are described. Section 4 presents the results of both performance and economic feasibility studies under current economic conditions, while a sensibility study is carried out under different future scenarios for the economic variables taking part in the analysis in Section 5. Finally, Section 6 sums up the main conclusions obtained throughout the whole study.

2. Spanish normative and economic framework

In Spain, during the last years, it has been the RD 661/2007 which has regulated the economic activity of electricity production under Special Regime [12]. This Royal Decree regulated both renewable and cogeneration based electric energy productions, ensuring a reasonable payment to the owners for their investments to get feasible [13].

However, all the remunerative complements were revoked with entry into force of the Royal Decree-Law 1/2012 on the suspension of the procedures of retribution and omission of the economic incentives for new cogeneration and renewable installations for electric energy production [14], involving a moratorium in the legislation. Recently, a new Law on fiscal measures for the energetic sustainability (LAW 15/2012) has been approved [15], establishing a new tax for electric energy producers taking part in the different engagement modalities of the electric energy production market. Nevertheless, the in-pass situation has not been settled yet.

In this sense, a forthcoming new Royal Decree, together with the RD 1699/2011 which regulates the connection to grid of low power electricity production installations [16], is expected to solve the baffling situation in which the cogeneration is submerged, establishing the regulation of the administrative, technical and economic conditions of the so called Electric Energy Supply with Net Balance [17].

On the other hand, electricity and natural gas acquisition prices are determined by the Ministry of Industry, Energy and Tourism, through tariffs called TUR. In case of natural gas, tariffs are updated quarterly, provided that there is a variation in the cost of the raw material greater than $\pm 2\%$ [18]. Electricity tariffs are modified quarterly as well [19].

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