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Hybridization of concentrated solar power plants with biogas production systems as an alternative to premiums: The case of Spain

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ABSTRACT

The present research explains and analyses a technically feasible and economically profitable alternative for concentrated solar power plants recently constructed in Spain. The proposed solution is hybridization with biogas. The method is more economical than investment in salt storage systems, used to improve operation time and a better electrical production control. This alternative proposes new income alternatives for plants by using residual heat in flue gases from boilers and in the cooling circuit in the power block, thereby achieving an effective reduction in the final cost of electric power generation. Current commercial technologies used in the bio-digestion process of organic waste are studied and practical cases that can be best integrated are analyzed. Presented case studies are presented for solar power plants without storage analyzing waste availability for biogas production. Areas with the greatest potential for the implementation of the proposed alternative and improvements aimed at increasing the overall performance of future hybrid plants are also determined, and an economic evaluation of the proposed solution versus salt storage is conducted. To improve research results a sensitivity analysis to evaluate the feasibility in different economic scenarios is performed. Results show that the proposed method of hybridization through the use of biogas provides an alternative solution for an important part of renewable generation power plants with a limited ability for dispatchability. In terms of environmental issues the solution places a value on certain types of waste that today, in addition to not being utilized properly, pose a serious problem for society.

Contents

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Nomenclature

AINIA Agrofood Industry Research Association (Asociación de Investigación de la Industria Agroalimentaria)
Alperujo 2F Alperujo (two-phase olive mill pomace) from two-phase oil-extraction process
Alperujo 3F Alperujo (three-phase olive mill pomace) from three-phase oil-extraction process
BP biogas plant
BR biogasification reactor
BTA biotechnische abfallverwertung (biotechnological waste utilisation)
CSP concentrated solar power
DDGS dried distillers' grains with solubles
DRANCO dry anaerobic composting
GHG greenhouse gases
HTF heat transfer fluid
IDAE Spanish Institute for Diversification and Energy Conservation (Instituto para la Diversificación y el Ahorro Energético)
INE Spanish National Institute of Statistics (Instituto Nacional de Estadística)
IOWM integral organic waste management
ISCC integrated solar combined cycle
ITC investment tax credit
IWES Institute for Wind Energy and Energy System Technology
IWTP industrial wastewater treatment plant
LNG liquefied natural gas
LPG liquefied petroleum gas
MARM Spanish Ministry of Agriculture, Rural Areas, and Environment (Ministerio de Agricultura, Medio Rural y Medio Ambiente)
OFMSW organic fraction of municipal solid waste
PTC parabolic trough collector
STP standard temperature and pressure
TES thermal energy storage
UASB upflow anaerobic sludge blanket
UWTP urban wastewater treatment plant
VS volatile solids

Formulae

$\%CH_4$ methane content in biogas (%)
CSP_{biogas} biogas required energy (MW h)
E_{biogas} specific final energy production (kJ/kg)
$E_{digestate\ management}$ specific energy consumption for digestate management (kJ/kg)
$E_{digestate\ transport}$ energy consumption for digestate transport (kJ/kg)
$E_{digestate\ transport}$ specific energy consumption for digestate transport (kJ/kg)
E_{plant} specific energy consumption for biogas plant operation (kJ/kg)
$E_{transport}$ specific energy consumption for digestate transport (kJ/kg km)
LHV_{CH_4} LHV for methane (kJ/m^3)
LHV_{biogas} LHV for the produced biogas (kJ/m^3)
P_{boiler} boiler rated power (MW)
V_{biogas} estimated biogas production (m^3)
$V_{biogas-CSP}$ annual biogas demand for the hybrid CSP plant (m^3)
m_i mass of digestate i (kg)
p_i specific biogas production ratio for digestate i (m^3/kg)
d distance from CSP plant to digestate source (km)

1. Introduction

Spain is currently the top producer of concentrated solar power (CSP) energy worldwide. The nearly 1878 MW h [1] of solar power energy produced in Spain in 2012, 73% of the worldwide CSP production, as well as leadership in projects in foreign countries, have positioned Spanish companies such as Abengoa and Acciona as model companies at the global level in construction and exploitation of this type of power plant. As an example, Abengoa is currently building the two largest concentrated solar power plants in the world, each of which will provide a rated power of 280 MW in the states of Arizona and California and the largest CSP tower in the world in South Africa, with a rated capacity of 50 MW. Spanish company Acciona broke the nearly 20 year hiatus in the construction of concentrated solar power plants in the U.S., thanks to its Nevada One project (State of Nevada) [2].

CSP plants require, for an adequate profitability and feasibility, ample solar resources. This requirement justifies the abundance of this type of power plants in the southern half of Spain, specifically the regions of Extremadura, Castilla-La Mancha, and Andalucía [3]. Within these regions, the majority of solar power plants are located in rural areas, where land prices are lower and large surface are available. These locations are often in regions with an abundance of agricultural and livestock waste. Analyzing the availability of organic waste in these areas where CSP plants are located, a significant energy potential was identified due to the abundance of agro-livestock waste [4], industrial waste, the organic fraction of municipal solid waste and sludge from wastewater treatment plants. Moreover, in these regions, abundance of this organic waste and lack of treatment and management strategies has also caused serious environmental problems. One of the most important examples is the case of eutrophication of the La Colada dam in Córdoba [5]. In the present paper the authors analyze the possibility of hybridization between CSP plants and biogas plants (BP) via the use of organic waste that is available in the zone of influence.