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Effect of different economic support policies on the optimal synthesis and operation of a distributed energy supply system with renewable energy sources for an industrial area

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ABSTRACT

Economic support policies are widely adopted in European countries in order to promote a more efficient energy usage and the growth of renewable energy technologies. On one hand these schemes allow us to reduce the overall pollutant emissions and the total cost from the point of view of the energy systems, but on the other hand their social impact in terms of economic investment needs to be evaluated. The aim of this paper is to compare the social cost of the application of each incentive with the correspondent CO_2 emission reduction and overall energy saving. A Mixed Integer Linear Programming optimization procedure is used to evaluate the effect of different economic support policies on the optimal configuration and operation of a distributed energy supply system of an industrial area located in the north-east of Italy. The minimized objective function is the total annual cost for owning, operating and maintaining the whole energy system. The expectation is that a proper mix of renewable energy technologies and cogeneration systems will be included in the optimal solution, depending on the amount and nature of the supporting policies, highlighting the incentives that promote a real environmental benefit.

1. Introduction

Distributed energy generation is a cost-effective alternative to the conventional supply of heat and electricity, especially for industrial users [1]. The integration of renewable energy sources (RES) into the system allows users to achieve higher economic and energy savings [2]. Considering that industrial users are characterized by quite predictable energy demands throughout the year, the adoption of such smart solutions leads to improving the energy efficiency of the system and thus to reducing primary energy consumptions and polluting emissions.

However, industrial stakeholders generally make their decisions looking for the minimum cost solutions, while environmental issues such as the greenhouse effect and the availability of energy resources should be evaluated as much as the economic aspect of the problem [3]. To promote a more efficient energy usage and the growth of renewable energy technologies economic support policies are widely adopted in European countries.

The objective of this paper is to evaluate the effect of different economic support policies on the optimal configuration of the energy supply systems and to compare the pollutant emission reduction and energy saving achieved by each incentive with its economic cost for society. The objective function to be minimized represents the total annual cost for purchasing, operating and maintaining the whole system, considering also the cost reduction for industrial stakeholders associated to the support scheme. The evaluation is carried on using as reference the distributed energy system designed to supply electricity and heat to nine factories belonging to the PonteRosso Industrial Area (San Vito al Tagliamento – Italy). Due to the complexity of the system, the minimum cost solutions have to be obtained adopting the configuration and the operation (including dispatch strategy) that result from the simultaneous optimization of the whole energy supply system [4,5].

Various subsidies related to the adoption of energy saving technologies are analysed: the capital cost reduction for cogenerators and solar thermal (ST) modules, special tariffs for electricity produced by biofuel cogeneration and photovoltaic (PV) panels, grants for fuel consumption and CO_2 emission saving (detailed references to the support policies implemented are given in chapter 3). The expectation is that a mix of cogeneration and renewable energies will be included in the optimal solution, depending on the amount and nature of the support policies adopted. Therefore, the

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Nomenclature

BOI	boiler	H_{boi}	boiler heat (kW h)
CCHP	combined cooling heat and power	HS	heat storage
c_{ep}	purchased electricity price (€/kW h)	H_{st}	solar thermal field heat (kW h)
c_{es}	sold electricity price (€/kW h)	i	interest rate
c_{fuel}	fuel price (€/kW h)	I	support policy (€)
CHP	combined heat and power	ICE	internal combustion engine
C_{inv}	annual investment (€/y)	Inv	total investment (€)
C_{man}	maintenance cost (€)	MILP	Mixed Integer Linear Programming
CO_2	carbon dioxide	n	life span (y)
C_{ope}	annual operating cost (€/y)	PV	photovoltaic
C_{tot}	total annual cost (€/y)	RES	renewable energy sources
DHN	district heating network	rf	capital recovery factor (y^{-1})
E_{cog}	cogenerated electricity (kW h)	S_{boi}	boiler size (kW)
E_p	purchased electricity (kW h)	S_{cog}	cogenerator size (kW)
E_{pv}	photovoltaic electricity (kW h)	SP	support policy (€)
E_s	sold electricity (kW h)	ST	solar thermal
EU	European union	t	time interval
F	fuel consumption (kW h)	TC	Traditional Case
H_{cog}	cogenerated heat (kW h)	j	component

incentives that promote real environmental benefit at an acceptable cost are highlighted.

The algorithm used to solve the system optimization comes from long research work in the field of low-impact generation systems and is the result of the evolution of previous Mixed Integer Linear Program (MILP) models, developed by the authors in other recent studies. An example of this kind of model for the optimal power generation and energy management for off-grid systems is also described by Dai and Mesbahi in [6].

First a MILP model was used by the authors to optimize the configuration and operation of cogeneration (CHP) and trigeneration (CCHP) systems for tertiary service buildings in [7–9]. That original model, with appropriate changes and introducing the thermal inertia of the district heating network (DHN), was then adapted to the PonteRosso Industrial Area [10]. A solar district heating system including a heat water storage (HS) was added in [11], while [12] describes a multi-objective optimization of the energy system, at the same time minimizing the total annual cost and the CO_2 emissions. All the users' configurations need to be optimized simultaneously due to the heat flowing through the various components of the system and the utilities themselves. This is one of the reasons why the MILP model developed in the study is optimized by considering the whole energy supply system as one indivisible entity. However, it is not difficult to find in literature cases where cogeneration systems of various concepts are designed and optimized to serve a single user [13–15]. An example of optimization model for industrial district heating networks is developed by Chinese et al. [16], while Lozano et al. [17] presents the thermoeconomic cost analysis of central solar heating plants combined with seasonal storage.

2. Optimization model

Several recent studies on the design and operation of energy supply systems are available in literature [18–23]. There can be many different systems including various options: centralized and decentralized machines, cogeneration and trigeneration units, renewable sources, DHN, etc.

Linearizing the performance curves of the cogenerators (the relationships between input and output streams), the MILP model is still a valid way to represent the system analysed [24,25]. In fact the other constraint equations of the model are linear: energy and cost balances are inherently linear while solar modules and boilers can be regarded as components with constant efficiency. Also the heat losses of the HS and the DHN are obtained as a fixed fraction of the hourly thermal energy stored in the respective component. In [26] a complete explanation of the MILP model developed in the paper can be found. The model is consistent with the algorithmic approach presented by Frangopoulos et al. in [27].

The first step towards optimizing an energy supply system is to define a superstructure: a representation of the system itself that encompass every single machine and component which might appear in the final optimal configuration.

The superstructure of the case study is represented in Fig. 1. The supply system has to provide the heating and electric energy needed by a set of industrial users. The energy demands are known in advance and considered constant in each time interval. The electricity can be produced by CHP units, both distributed (placed in the site of each user) and centralized, by a central solar PV plant or can be purchased from the external grid. The required heating energy can be produced by CHP units, by conventional boilers or by a centralized ST field. Looking at the superstructure, a general user may include only a CHP and a boiler while in the central unit a cogenerator, a boiler, the HS, the ST modules and the PV panels may be installed. The users are connected together and to the central unit through a DHN of predefined layout and design. As the DHN connects the factories, the heat produced by central and distributed units can be self-consumed, exchanged between the users or sent to the HS.

A system that includes a ST field and a HS connected to a DHN is called a solar district heating system. Practical examples of such a configuration can be found in central and northern European countries and are designed to supply heating energy both to residential and industrial buildings, allowing a solar fraction of 50% [28]. The main advantage of those systems is the possibility of storing the energy in the form of hot water and using it when needed. Another characteristic is usually a low specific investment cost, mainly because of the large scale of the plant.

The MILP model developed in the paper is quite flexible and the equations can be adapted to different case studies simply by varying component performance parameters and energy vector prices.

2.1. Objective function

The aim of the model is to minimize the total annual cost for owning, operating and maintaining the whole energy supply system. The objective function C_{tot} is linear and its expression is: