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Assessing the feasibility of cogeneration retrofit and district heating/cooling networks in small Italian islands

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ABSTRACT

Sustainability of energy supply in small islands has been emerging as a severe issue, due to the large margins for improvement of the most frequently adopted solutions. In many European islands large amounts of heat are wasted by the operation of engines-based power plants; conversely, heat is produced by boilers or by electric equipment for different uses, like domestic hot water or space heating. In this paper a techno-economic analysis is proposed to assess the feasibility of CHP-retrofit of existing power plants and the possible utilization of the recovered heat to supply, via a district heating and/or cooling network, the energy requests of civil users in the tertiary and residential sectors. The analysis is performed for six islands in Italy characterized by different demographic and climatic conditions, so as to get a comprehensive understanding of the factors that favour/obstruct the viability of the examined technical solution. As expected, due to the low "linear heat density" observed in small islands, the investments resulted "far from being attractive"; only in the case where public support mechanisms are adopted, the integration of the existing power plants with heat recovery devices and a district heating network resulted moderately attractive, especially in the largest islands.

1. Introduction

Sustainable energy supply in remote areas like small islands represents an emerging research topic [1], since in many sites obsolete technologies and scarcely efficient energy uses may be encountered. In this regard, recent studies have suggested the use of integrated approaches to sustainability [2], aimed at addressing the need for efficient energy supply by adopting appropriate mix of efficient technologies [3]. The contribution of Renewable Energy Sources (RES) to the total energy supply in small islands has been often limited by grid stability concerns. In fact, though a large number of renewable sources is often available [4], most of small islands are not or are only partially connected to continental electrical networks and consequently appropriate management of energy supplies is required to reach a perfect balance between instantaneous production and demand and sufficient electric grid safety standards. In a recent paper a detailed survey was conducted for the French islands [5], pointing out that RES potential is often underused, accounting for a share between 5% and 45% (with a 20% average) in terms of installed capacity and between 2% and 30% (with a 10% average) in terms of annual production. In particular, difficulties emerge with the increasing penetration of intermittent energy sources (like solar photovoltaics and wind energy), characterized by high intermittence levels and stochastic behaviour; when such sources are not available, in fact, other generation units have to compensate the lack of power and, consequently, sufficient reserve margins must be ensured (units supplied by fossil or predictable-renewable sources and already in part-load operation). Moreover, national and local regulations targeted to landscape planning issues have to be taken into account in order to verify the actual possibility to install RES plant.

Relevant studies have been published for a number of islands, such as Northern Cyprus, where the energy system is 90% dependent on oil products, with a moderate contribution to the total supply by coal and solar energy, and with a further criticism deriving from the average 7% annual increase in the energy consumption observed along the last decades [6]. Research activities have been estimating the potential benefit from an increased use of RES technologies, with a particular focus on wind, solar and biomass energy, aimed at ensuring cost abatements (due to the avoided fuel costs) and reduction in environmental impacts. Ikan

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et al. [7] also focused on the potential of possible "demand management" actions aimed at modifying the electric load profiles in the Island. In order to increase the installed capacity and face the continuous growth in demand peak, the same authors demonstrated the economic viability of photovoltaic and wind systems in the Cyprus context. Despite all these desirable previsions and the relevant role recognizedly played by Cyprus in Solar Thermal technologies, Pilavachi et al. [8] underlined that a more rational energy use in Cyprus is needed and that RES inclusion targets are still to be achieved. Indeed, high RES penetration in small islands can only be achieved by implementing specific strategies based on combination of a mix of renewable sources and storage options (also requiring high investments), as observed for instance in the Canarian island "El Hierro" which today represents a worldwide benchmark for the implementation of energy self-sufficiency based on clean energy sources [9].

Although advances in energy storage technologies are expected to weaken the concerns related with grid stability in the medium-term, most of the energy systems currently installed on small islands have the following in common:

- A higher rate of exploitation of deterministic renewable energy sources (depending upon their local availability), such as hydropower [10] and biomass [11], compared to the aforementioned intermittent ones. In a very few cases, an appropriate mix of stochastic and flexible/predictable renewable energy sources has allowed to achieve very high RES penetration levels [12];
- The largest share of energy supply by diesel or heavy fuel oil, used in internal combustion engines. This result, that has been verified by an extensive survey conducted at European Union (EU) level examining a significant number of small islands out of the 286 located within the EU territory [13], is due to a number of factors, such as: (i) the relative easiness with which fuel can be purchased and supplied (compared to less attractive alternatives, such as natural gas to be transported either by pipelines or liquefied by tankers), (ii) the flexibility of engines (especially when designed by a modular approach) in meeting the daily and seasonal variations in energy demand.

Nonetheless, in spite of the high share of installed power generation capacity by diesel oil-fuelled Internal Combustion Engines (ICEs) and of the highly strategic outcomes that could be achieved for small islands [14] the penetration of ICEs-based Combined Heat and Power (CHP) in small islands is very low. This is mainly due to the following factors:

1. The difficulties in exploiting the recovered heat to supply a useful heat demand. Residential and non-domestic energy users are often disseminated over large areas (eventually characterized by complex orography), with a very low demographic density, thus making the viability of District Heating (DH) or Cooling (DC) networks hard to be achieved;
2. The heat requests highly fluctuate on a seasonal basis. In many Mediterranean islands the heat loads for space heating are quite low, both because of the mild climate and the small share of permanent residents (compared to the annual peak of presences), especially in sites with a touristic vocation.

In a recent document assessing the CHP potential in Malta [15], it is clearly stated that feasibility of a small-medium scale district heating (and cooling) network is a preliminary condition to favour the penetration of cogeneration or trigeneration; in the same work two main barriers to the spread of district heating are identified: (i) the prevalent use of electric heating in stand-alone residential users, due to the absence of natural gas grids, (ii) the short space heating season due to the mild climate.

Although district heating represents a well-consolidated technological solution, with a high penetration especially in densely populated areas and cold climates, intense research activities have been conducted in the last few years as concerns possible improvements or identification of context-oriented design solutions. Čulig-Tokić et al. [16] presented a comparison between two different district heating systems serving two towns, Zagreb (Croatia) and Aalborg (Denmark); evident asymmetries were observed in terms of heat supply sources, total network length, supply temperatures and cost charging criteria for customers. In the search for the so-called 4th Generation District Heating concept [17], intended as systems which could operate as smart thermal grids and contribute to sustainability of energy supply, one of the main trends consists in gradually lowering the water supply temperature, so as to reduce heat losses and increase the overall efficiency of the energy conversion chain. Ommen et al. [18] analysed the positive impacts of low supply temperatures, in terms of increased efficiency of Combined Heat and Power systems eventually supplying the network (accounting for different power plant technologies) and overall results from the primary energy saving and CO_2 emissions viewpoints. In a recent paper, Østergaard and Lund [19] developed a technical scenario where the assumption of very low supply temperature was formulated to allow exploiting the large amounts of low temperature geothermal energy and thus converging toward the declared goal of making the Danish city Frederikshavn a 100% renewable energy city.

The present paper is aimed at evaluating some specific technological solutions (based on cogeneration/trigeneration and district heating or cooling) to increase the energy efficiency in small islands, with a particular focus on six islands in Italy. The ambitious goals declared in the above referenced works (like the 100% renewable energy scenario) become, for small islands, absolutely far away from being realistic. In fact, in most of small islands the state of art reveals the presence of different poor energy uses and an extremely low penetration of renewable sources. Then, the perspective of the research and the aim of the present study are rather different than the one behind the cited papers: here the feasibility of DH/DC networks will be investigated only as a means to allow exploiting part of the enormous amounts of waste heat currently discarded, with no useful scope, by the power generation units (prevalently based on diesel generators) that supply electricity to these remote communities. It is evident that the technological solution examined in this paper represents only one of the several options available for a more sustainable energy supply in islands. Several works have demonstrated the potential of other options, such as the use of solar thermal energy, for cooling and heating purposes. An interesting example is represented by the combined use of Concentrating Solar Power (CSP) and Organic Rankine Cycles; a demonstrating plant has been installed in Ottana (Sardinia, Italy), where a more complex and efficient lay-out also includes a Concentrating photovoltaic system (CPV) and an electrochemical storage. In this cited example, the control systems resulted to represent a crucial point in order to fulfil the desired power generation profile in accordance with weather forecasting [20]. Also more innovative solutions might be considered, such as the Ocean Thermal Energy Conversion (OTEC); the proven potential of this technology is still scarcely exploited [21], but some recent studies have been developed for the Reunion Island [22] and for Eastern Caribbean Small Island [23], demonstrating that feasibility could highly benefit of some specific economical and technological conditions.

The reasons for having focused the proposed analysis only on a specific technology (i.e. engines-based polygeneration coupled with district energy supply) is related with the objectives of the

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