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Energy, economic and environmental analysis on RET-hydrogen systems in residential buildings

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Abstract

The aim of this study was to analyze energy, economic and environmental performances of a set of scenarios dealing with the production and the use of hydrogen as energy carriers in residential applications in combination with renewable energy (RE).

The authors also made an investigation into the required economic conditions necessary for making H_2–RE residential systems competitive with conventional ones, which are based on the use of grid electricity and natural gas.

A case study was enacted in a small residential district in Palermo (Italy) made by five multi-storey buildings.

Many energy systems have been considered according to several fuel-device combinations (electric grid, fuel cell, PV panels, wind turbines, boiler etc.).

The software HOMER (hybrid optimization model for electric renewables), developed by NREL and Midwest Research Institute (USA), was used, in order to study the energy balance of the system and its components. Moreover, it was possible to simulate the hourly operation of each system and to calculate technical, economic and environmental performance parameters.

The net present cost and the cost of energy are the two main parameters used to compare economic performances of the systems with both actual and expected costs in the medium term.

A sensitivity analysis was carried out in order to appreciate the most important parameters influencing the economic performances of the systems and to define possible future scenarios of competitiveness between technologies.

Emissions of CO_2 (the most important greenhouse gas) and other pollutants have been considered for an environmental benefits analysis.

Keywords: Hydrogen; Renewable energy technologies; Economics; Environmental performances

1. Introduction

Hydrogen production represents one of most promising solutions for solving the problem of intermittence in the power production by renewable sources by reducing local impacts of energy conversion and diverting it to several final uses.

Hydrogen is a clean energy carrier. It can be produced by electrolysis of water using electricity generated by renewable energy (RE). Electrolytic hydrogen is made from water and is recycled as water. Its oxidation in fuel cells gives an output of electricity and water. Only when hydrogen is not recombined with pure oxygen, and air is used as the oxidant instead, such as occurs in engines or gas turbines, is nitrogen oxide produced [1,2]. Moreover, the reaction among the oxygen and the nitrogen in the air can produce much lower emissions of nitrogen oxides than the combustion of fossil fuels [3].

The market penetration of technologies based on hydrogen conversions requires large technological and infrastructural changes. Geopolitical implications could be enormous. Shifting from fossil fuel to the plentiful and more dispersed hydrogen could alter the power balances among energy-producing and energy-consuming nations, possibly turning today's importers into tomorrow's exporters [4]. Fulfillment

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of this target depends on social, environmental and economic concerns. It is well known that there is an increasing interest in environmental themes and the chance to obtain higher environmental performance with the same distribution of power, which could be directed toward a more wide employment of clean technologies.

The use of RE systems in remote, off-grid areas is fairly well established around the world. Applications include telecommunication stations, single homes and small villages. Cotrell et al. [5] have concluded that fuel cell systems supplied with electrolytic hydrogen produced by wind turbines (WT) and photovoltaic (PV) systems appear competitive in a 148-kW village power system if fuel cells price is reduced to 40% of their capital cost [5].

Santarelli et al. [6] have established that the costs of a PV-hydrogen system feeding a residential building in an isolated valley of the Alps are not competitive in the actual energy market, and only considering the elimination of the costs of the distribution medium, voltage lines, and external cost due to pollution, the competitiveness of this system should be increased.

Many experts foresee hydrogen produced by non-fossil, RE sources to be technically, economically and ecologically relevant in the next 20 years. However, hydrogen will not be a suitable or economically feasible energy carrier for all markets and countries, so that the use of methanol and synthetic liquid hydrocarbons in fuel cell vehicles or natural gas for stationary fuel cell applications, with reformed technology for central or on-site hydrogen generation, will have an important role in the energy supply. Lokurku et al. [7] compared electricity generation costs of a 200 kW_e combined heat and power (CHP) natural gas–fuel cell system with a conventional CHP package having identical electrical power for stationary use. They found that natural gas–fuel cell systems for CHP will be competitive with an 80% investment and maintenance cost reduction and by improving fuel cell performance (increasing stack running time and efficiency).

This paper analyses the use of hydrogen technologies in residential buildings connected to an existing electric grid. The aim of the study is to investigate the economic and environmental impacts of the use of hydrogen fuel cells as a substitute for electricity provided by grid and heat from a gas boiler. The building is thought of as a self-sufficient system, and the electric grid represents only an emergency device that operates when the fuel cell is not running (for breakdowns or maintenance).

A small residential district has been studied. where a conventional energy supply system was used as a "base system" and some alternative systems operating with the H_2 carrier were designed.

HOMER [8] has been used to simulate the operation of the system and to calculate, for each configuration, several technical, economic and environmental parameters.

The main economic indicator used to compare the system is the "net present cost (NPC)," which is the present value of the costs of investment and operation of a system over its lifetime.

CO_2, CO, NO_x, SO_2, unburned hydrocarbons and particulate matter are indicators used to analyze the environmental performances of each system.

A comparison among conventional and hydrogen systems has been done.

2. Analysis of study cases

Five identical buildings in a neighborhood located in Palermo (South of Italy) have been considered to be representative of a small residential district. Each of these buildings has five floors with four apartments. The floor area of the typical apartment is 70 m^2 (Fig. 1 and Table 1). They are presumed to be occupied by an average of four persons.

3. Calculation of electric and thermal load

Assessment of electricity consumption due to household appliances and lighting devices led to several assumptions about quantity and use of devices inside apartments, stairwells and basements. Six "typical days" (*cool*, *intermediate* and *hot* days evenly subdivided into *working days* and *holidays*) were defined, together with appropriate utilization schedules. As an example, a time-profile of electricity use for a "cool working day" is reported in Fig. 2.

A typical year's consumption series was the result of the time combination of its typical days (Fig. 3).

Heating and cooling thermal loads were estimated using the software TRNSYS [9].

In order to assess the energy demand, two different reference configurations of HVAC systems were considered.

A. *Heating* and *cooling* are provided by a centralized heat pump connected to 60 fan coils (three for each flat).
B. *Cooling* is provided by a chiller connected to 60 fan coils, and *heating,* by a natural gas boiler (one for each flat)

In the first case, simulation outputs included the heat pump's electric energy demand for heating and cooling. Total energy consumption was the result of the addition of electrical devices and heat pump consumption.

In the second case, simulation outputs included the chiller electrical energy demand for cooling and the heating thermal load which would have needed to be covered by natural gas. Total energy consumption included electrical energy consumption due to electrical devices and chiller and the amount of natural gas used by the boiler.

Fig. 4 shows total thermal loads of the group of apartments.