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District heating systems based on low-carbon energy technologies in Mediterranean areas

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ABSTRACT

Heating and cooling are responsible for 70% of energy consumption in European buildings, with renewables covering only 18%. To reduce emissions in the building sector, district heating based on low-carbon energy is identified as a key technology for the transition to a low-carbon economy. However, currently only 16% of thermal district networks are based on biomass, and around 3.2% on solar. This paper analyses the application of solar and biomass district heating systems in the low-to-moderate population density areas of the Mediterranean. These areas are characterised by high solar and biomass availability, and lack of space restrictions, along with particular challenges for implementation. A methodology for viability analysis and optimised integration is presented. The methodology is applied to a case study in the south of Spain. The results show that with a linear heat density greater than 1.5 MWh/m, there could be viability with internal rates of return higher than 7.4 and 9.8%, and payback period below 13 and 10 years, for solar and biomass systems respectively. The use of seasonal thermal energy storage allows the solar fraction to be increased from 55 to 75%. Sizing and design strategies for their viable implementation in Mediterranean areas are extrapolated from the analyses.

1. Introduction

According to the International Energy Agency [1], buildings are the largest energy-consuming sector in the world, and they account for over one-third of total final energy consumption and an equally important source of carbon dioxide (CO_2) emissions. Moreover, if no action is taken to improve the energy efficiency of the sector, energy demand is expected to rise by 50% by 2050. In the European Union, buildings account for 40% of total energy consumption and 36% of CO_2 emissions [2], of which 70% is due to heating and cooling [1], with fossil fuels being responsible for 75% and renewables for only 18% (11% biomass; and 7% Wind, Photovoltaic, Solar and Geothermal) [3]. The Energy Efficiency Directive (EED – 2012/27/EU) [4] sets a common framework for the promotion of energy efficiency within the European Union. In addition, in February 2016 the European Commission published its first action plan to tackle the massive amount of energy used to heat and cool Europe's Buildings [3]. The Heating and Cooling Strategy includes actions to increase renewable energy use and the integration of DH/DHC systems, providing flexibility to the energy systems by reducing and shifting demand through thermal energy storage (TES) systems.

Providing energy services via renewable energy through DH/DHC networks can be simpler, more efficient and less expensive than direct integration into each individual building [5,6]. Thus, to reduce the energy dependence and emissions in the building sector, efficient district heating systems based on low-carbon energy (LCE) are identified as key technologies for a sustainable energy transition [7–11]. Pardo and Thiel [7] analysed different energy efficiency measures and reported that heating and cooling systems based on district heating had lower CO_2 emissions. Lund el al. [8] reported that in future renewable energy systems, the best solution will be based on the combination of a gradual expansion of efficient LCE/DH-DCH systems with individual heat pumps in the remaining houses. Handy et al. [9] showed that the implementation of efficient DH systems and solar thermal energy, along with local heat pumps, are key elements for reducing energy consumption. Zvingilaite and Balyk [10] showed that expansion of heat saving measures in Denmark, such as LCE/DH, allow a 40% reduction in energy consumption. In addition, the International Energy Agency [11] estimates that the implementation of LCE technologies for buildings will allow CO_2 emissions to be reduced by up to 2

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Nomenclature

a	Year of operation
$a_{Increase}$	Annual energy price increase (€)
ATES	Aquifer thermal energy storage
BD	Building density in the district network
BTES	Borehole thermal energy storage
C_a	Annual cash flow (€)
C_a^{system}	Individual system amortisation cost (€)
C_{fuel}	Fuel cost of DH system (€)
C_i^{system}	Individual system capital cost (€)
C_m^{system}	Individual system maintenance cost (€)
$C_{O\&M}$	O&M cost of DH system (€)
c_p	Specific heat (kWh/kg°C)
CAPEX	Capital expenditures
CG	Correction factor (%)
CHP	Combined heat and power
d_a	Average pipe diameter (m)
D	Energy demand (kWh)
DD	Monthly degree day value
DH	District heating
DHC	District heating and cooling
E	Energy demand per building (kWh)
E_{sold}	Total energy sold to the DH system (kWh)
F_i	Utilisation factor (%)
I	Investment cost (€)
IRR	Internal rate of return (%)
$K_{building}$	Building heat transfer constant
L	Pipe network length (m)
L_{base}	Reference baseline of average energy price (€)
LCE	Low-carbon energy
LHD	Linear heat density (GJ/m or MWh/m)
m	Mass of water (kg)
$n_{buildings}$	Number of buildings
NPV	Net present value (€)
O&M	Operating and maintenance
OPEX	Operational expenditures
$\rho_{buildings}$	Rate of buildings in the DH area (buildings/km^2)
p_{energy}	DH energy selling price (€/MWh)
P_{fuel}	Energy price of fuel (€)
P	Power demand (kW/m^2)
PBP	Payback period (years)
ROI	Return on investment
S	Building area (m^2)
SHW	Sanitary hot water
t	Temperature (°C)
t_c	Comfort temperature (°C)
T	Minimum temperature in the municipality at 99th percentile (°C)
T_{60}	Temperature at 60 °C (SHW)
T_{red}	Temperature of the water supply (°C)
TES	Thermal energy storage
TF	Time factor (%)
UTES	Underground thermal energy storage
η_{system}	System Efficiency
θ	Hour

gigatonnes (Gt) by 2050.

A DH/DHC system connects multiple energy consumers to cost-effective and environmentally optimal heat sources through a piping network. Currently, there are over 5000 thermal districts in Europe [12], which provide around 9–10% of the EU's energy needs [3], gas being the main primary energy source (40%), followed by coal (29%), biomass (16%) and solar (around 3.2%) [3,13]. More than half of these facilities are located in North and Northeast Europe [5], with Sweden being the country with the highest penetration of DH systems [14]. The scarcity of solar DH systems, above all in Southern Europe, is a surprising fact given the high solar energy and biomass availability. According to the European Large-Scale Solar Heating Plant Database [13] (developed within the European project named Solar District Heating), only 163 solar DH systems are registered in Europe, and most of those (around 75%) are located in Denmark, Sweden, Austria and Germany.

The viability and competitiveness of DH/DHC systems depend on several factors: investment costs of energy production system; distribution costs, which depend on network size and thermal load; customer connection costs; and difference between district heat supply and alternative local heat supply [15–17]. Therefore, DH/DHC systems tend to be more competitive for low investment cost systems, low operating and maintenance (O&M) cost technologies and high heat density.

Energy performance of LCE/DH technology has been demonstrated, and strategies for an optimal design are known. However, its viability is uncertain, and, in addition, small and medium-sized cities present additional challenges for its implementation. Thus, despite the great potential of renewable supply through DH in the Mediterranean areas, LCE/DH systems have hardly been implemented [3,13,18]. This generalised situation is due to the fact that LCE/DH systems viability is uncertain under low-to-medium population density and reduced season of heating demand (3–6 months), which extends the investment period of return. Also, for small and medium scale LCE-DH applications, the relative investment cost of a piping network is higher [19], and customer connection cost is higher when the project is retrofitted in a fully developed site [5]. As design considerations for low-to-medium population density areas, Nilsson et al. [20] showed that it is possible to enhance profitability in sparse district heating investments. The key is higher productivity through more efficient construction routines (cheaper investment costs) and more suitable methods of customer connections, rather than more efficient technologies. Reidhav and Werver [21] stated that if the local distribution system has low investment and marginal costs, the DH systems in sparse areas may be viable.

The impact of energy consumption in small and medium-sized cities in Europe is very high. A relevant proportion of European citizens live in intermediate (26%) and thinly populated areas (24%) [22]. They have differential urbanistic characteristics, needs and opportunities for the potential use of LCE technologies. Low-to-medium population density areas with a Mediterranean climate (such as municipalities from Southern Europe with low-to-medium population density – around 25000 population) are identified as potential candidates for viable DH systems, due to: i) relevant seasonal heating demand; ii) proximity of primary resources, such as biomass from agricultural and forestry residues [23]; iii) high solar availability (global average irradiance higher than 5.00 KWh/m^2·day) [24]; and, iv) space availability for renewables installations, such as solar collectors and geothermal systems, at moderate distances from supply nodes.

New knowledge and studies are required to define a viable framework for the integration of LCE-DH systems in low-to-medium population density areas in the Mediterranean region.

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