Decarbonizing livestock structures: retrofit of a pig barn using renewable sources

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Abstract

Livestock farming represents one of the most energy-consuming sectors of agriculture, currently causing significant GHG emissions. The necessity of replacing fossil fuels with Renewable Energy Sources (RES) is leading the scientific community toward the research of retrofitting strategies for existing farms, aimed to develop new equipment based on RES for the various farming activities. This study is focused on the development of sustainable heating systems for livestock barns, suitable to be adopted to replace fossil-based existing ones.

The research is carried out with reference to a pilot case represented by a swine farm located in northern Italy, rearing 500 sows and 2500 weaners. The study takes into consideration a nursery barn and consists in the design and test of an integrated RES system combining a photovoltaic-thermal plant, a geothermal storage, and a modular heat pump. A smart control system was developed and installed to monitor energy uses and environmental conditions.

The results demonstrate that the energy demand of a livestock farm can be met by a mix of RES properly defined, specifically designed to optimally exploit the renewable resources generally available in farming environments.

The study was developed within the innovation project RES4LIVE, running in the period 2020-2024 under the European program Horizon 2020.

Keywords: Zero-carbon, Pig barn, Heating system, Sustainable farming

1. Introduction

Fossil fuel use in farming has negative effects as a major source of greenhouse gas (GHG) emissions, with significant contributions to global climate change. One of the most energy-consuming sectors of agriculture is intensive livestock, which is mainly based on fossil fuel use. Both electricity and thermal energy are required to cover strongly diversified energy demands (Bilardo et al., 2019), such as cooling-heating of the indoor livestock buildings environment (Faes et al., 2021), powering equipment, lighting, and ventilation systems. With declining costs and improvement of reliability and performance of key renewable energy sources (RES) technologies, the opportunities for farmers to engage in RES production are increasing.

In this context, the innovation project RES4LIVE "Energy Smart Livestock Farming towards Zero Fossil Fuel Consumption", running in the period 2020-2024 under the call "Defossilising agriculture – solutions and pathways for fossil-energy-free farming" of the European program Horizon 2020, aims to develop integrated, cost-effective and case-sensitive RES solutions towards achieving fossil-free livestock farming. The project adapts and tests promising RES technologies in energy-intensive livestock farming to greatly reduce the fossil energy that is the main source used to cover the energy demand.

This study aims to define the technological solutions and the design solutions for the development of a sustainable heating systems for a pig barn, suitable to be adopted as replacement of fossil-based existing ones. The research is carried out with reference to a real study case where the solution developed are implemented. This s

2. Materials and Methods

Dedicated, optimal designs combined with energy efficiency and other solutions are proposed, demonstrated in pilot farms, as fundamental phases of RES4LIVE.

2.1. Design of the pilot system

The pilot case presented in this research is a swine farm located in Modena province (northern Italy), rearing 500 sows and 2500 weaners (Figure 1).

Figure 1. Satellite image of the pilot farm.

The de-fossilization project focuses on the nursery barn of the farm (Figure 2): in this building, we carried out the development and design of an integrated RES system combining a photovoltaic-thermal plant, a geothermal storage (Fiorentini et al., 2023), and a modular heat pump. This system is suitable to replace a 34 kW LPG boiler.

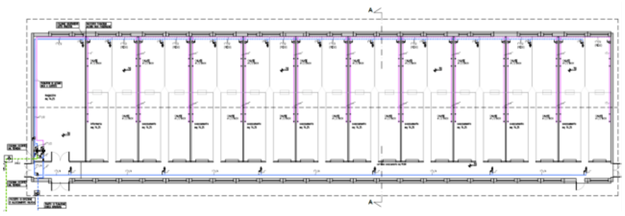

Figure 2. Plan layout of the nursery barn. The equipment is located in the technical room, the first on the left.

Specifically, the integrated system (Figure 3) is composed by photovoltaic thermal collectors (PVT), a dual source heat pump (DSHP) and a borehole thermal energy storage (BTES).

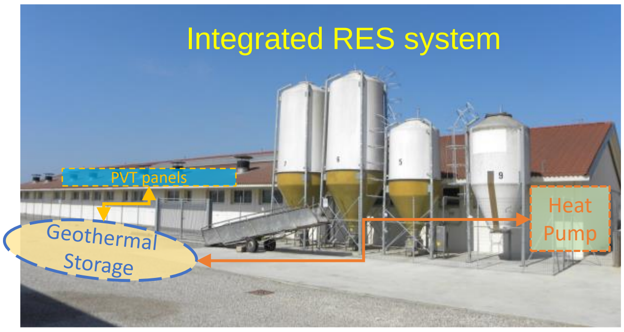

Figure 3. Scheme of the integrated RES system.

2.2. Geology and hydrology

An in-depth analysis of the geological and hydrological characteristics of the site was carried out to obtain the parameters needed for the design of the borehole thermal energy storage. The case study is located in the Po Plain, where alluvial sediments can reach 150 m and more. Up to that depth, no salt intrusion is expected, since the limit of marine deposits is set around 300 m of depth. Table 1 reports the stratigraphy.

Table 1. Stratigraphy of the study case.

Depth	Stratigraphy	Thermal conductivity
0-10 m	Silt and clay	0.03 m^2 d^{-1}
10-12 m	Sandy humps and clayey sands (aquitard)	0.07 m^2 d^{-1}
12-50 m	Sand (aquifer, confined)	0.10 m^2 d^{-1}
≈ 50 m	Clay and clayey sands	0.03 m^2 d^{-1}
50-80 m	Sand (aquifer, confined)	0.10 m^2 d^{-1}
80-100 m	Clay and clayey sands	0.03 m^2 d^{-1}
> 100 m	Sand (aquifer, confined)	0.10 m^2 d^{-1}

Confined aquifer can be found around 10 m (approximately correspondent to the top of first aquifer). In deep wells nearby the case study, the groundwater level is around 10 m. On the other hand, it is expected that, drilling down to the aquitard and the top of the confined aquifer, the groundwater level reaches from 1 to 3 m depth, due to capillary action and varying with seasonality. In any case, groundwater movement in the aquitard is very low. In the aquifer, hydraulic conductivity is very high, reaching 10^{-4} m/s, while porosity is between 30% and 40%. In the aquitard, due to low conductivity and relatively high porosity, it is expected a high specific storage. The water flow follows direction East-West.

3. Results and Discussion

The results of the design and implementation phases of the BTES system are reported as follows.

3.1. Implementation of the geothermal storage

Two piezometers 2" wide, 25 m deep and distant each other 40 m, were installed, in a line over direction North-South. Between the two piezometers, two double U, PE100 PN16 DN32, BHE were installed, the first one 10 m deep (crossing the first layer of clay with sandy lens), while the second one 30 m deep (crossing the second layer of fine sand, hosting the shallow aquifer). Two thermal response tests (GRT) were performed, one per each BHE, while temperature and hydraulic head values were taken in the observation boreholes, by using both fixed recording sensors and movable measurements tools.

3.2. Borehole Thermal Energy Storage dimensioning

The data gathered and the results of the tests have been used to select the most suitable working depth for the BTES field, to quantify the potential for underground thermal storage, to understand the heat dispersion due to groundwater movement and to model the BTES behaviour under various operation scenarios. The results led to adopt 30m Borehole Heat Exchangers (BHE) as most efficient solutions. Based on the dimensioning of the integrated system, 8 BHEs proved suitable for the energy storage and thus they were drilled to make the BTES (Figure 4).

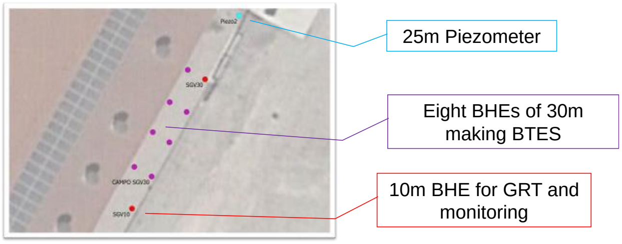

Figure 4. Plan layout of the BTES field.

4. Conclusions

The conclusions obtained are applied in the design phase to optimize the integration of PVT, BTES and DSHP. The results demonstrate that the energy demand of a livestock farm can be met by a mix of RES properly defined, specifically designed to optimally exploit the renewable resources typically available in farming environments.

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