Second set of practice abstracts

Deliverable 7.9

WP7. Dissemination, Communication, Exploitation

Project title

RES4LIVE - Energy Smart Livestock Farming towards Zero Fossil Fuel Consumption

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X	PU = Public
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Author/s	EAAP
Task Leader	EAAP
WP Leader	CETRI

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ABBREVIATIONS

PA	:	Practice Abstract
EIP-AGRI	:	European Innovation Partnership for Agricultural Productivity and Sustainability

PARTNERS SHORT NAMES

AUA - AGRICULTURAL UNIVERSITY OF ATHENS

UNIBO – UNIVERSITY OF BOLOGNA

ATB - LEIBNIZ INSTITUTE FOR AGRICULTURAL ENGINEERING AND BIOECONOMY

EV ILVO - RESEARCH INSTITUTE FOR AGRICULTURE, FISHERIES AND FOOD

UGENT - GHENT UNIVERSITY

CERTH - CENTRE FOR RESEARCH AND TECHNOLOGY-HELLAS

AU - AARHUS UNIVERSITY

LVAT - LEHR- UND VERSUCHSANSTALT FÜR TIERZUCHT UND TIERHALTUNG GROß KREUTZ E.V.

PSYCTOTHERM - G. LIGEROS & SIA OE

PLEGMA LABS- PLEGMA LABS TECHNOLOGIKES LYSEIS ANONYMOS ETAIRIA

CRMT SAS - CENTRE DE RECHERCHES EN MACHINES THERMIQUES

TERRA - TERRA ENERGY

MG SUSTAINABLE - MG SUSTAINABLE ENGINEERING AB

CETRI - CENTER FOR TECHNOLOGY RESEARCH & INNOVATION LTD

GOLINELLI - GOLINELLI GIULIO

EAAP - FEDERAZIONE EUROPEA PER LA ZOOTECNICA

EUREC - EUREC EESV

PUBLISHABLE SUMMARY

A practice abstract (PA) is a short summary, in understandable language, that describes the main information/recommendation/practice that can be used by the end-users in their daily practice.

This compilation of practice abstracts aims to highlight farm and research-led innovations that demonstrate ways to improve the welfare of livestock and, at the same time, the efficacy and affordability of renewable energy farming systems. Each practice abstract will be produced in English and, if applicable, in national languages, for broader dissemination purposes.

In the framework of the RES4LIVE project, thirty (30) PAs have been produced in the EIP Agri format. These practice abstracts have been produced and grouped in two sets, respectively reported in two deliverables:

- D7.8 First set of practice abstracts submitted at Month 18, containing ten (10) PAs;
- D7.9 Second set of practice abstracts submitted at Month 49, containing twenty (20) PAs.

With the support of the coordinator and WP leaders, a preliminary list containing about fifty (50) potential PA abstracts and relevant responsible partners was drafted. EAAP contacted the partners guiding the drafting of the PA.

Per each practice abstract, two versions have been created:

- One version to be used for the EIP-AGRI database, available on the CAP Network website without pictures;
- One more detailed version was published on the RES4LIVE website (with illustrative pictures).

The thirty (30) PAs have been already published on the RES4LIVE public website (see Annex 1) under Communication and Dissemination/Practice abstracts (https://res4live.eu/practice-abstracts) using a specific template designed by EAAP. Relevant posts were done on project social media accounts (Twitter, Facebook and LinkedIn). The first ten (10) PAs have been also sent and stored for publication on the EU CAP Network website (https://eu-cap-network.ec.europa.eu/projects/res4live-energy-smart-livestock-farming-towards-zero-fossil-fuel-consumption_en#tab_id=practice_abstracts) along with the relevant project information. The following twenty (20) PAs have been sent to EU CAP Network website staff and will be soon listed on the same page mentioned above. The following PA were elaborated:

- The first set of practice abstracts (10) – more details available in D7.8 "First set of practiceabstracts"

PA	Title	Partner
PA01	Heat pumps for climate control of livestock buildings	PSYCOTHERM
PA02	Laying hens' thermal comfort and egg productivity	AUA
PA03	Precise indoor environmental control of agricultural buildings and energy smart control	PLEGMA
PA04	Thermoneutrality in dairy cattle and its effect on productivity	ATB
PA05	Pigs' thermal comfort and the relationship with productivity	EV ILVO
PA06	On-farm energy demand and available renewable energy potential in pig farms	UNIBO
PA07	Photovoltaic - Thermal collectors for electrical and thermal demands in livestock farms	MG

PA08	Electric tractors (e-tractors) for on farm use	CERTH
PA09	On-farm energy demand and available renewable energy potential in poultry farms for egg production	CERTH
PA10	On-farm energy demand and available renewable energy potential in dairy farms	CERTH

- The second set of practice abstracts (20):

PA	Title	Partner
PA11	Adaptation of a diesel farm tractor for biomethane use	CMRT, ATB
PA12	Borehole Thermal Energy Storage system for swine farm	UNIBO, GOLI
PA13	On-farm Biogas to Biomethane upgrading plant and filling station	ATB
PA14	Open barn ventilation system for a dairy cattle farm	ATB, LVAT
PA15	Domain decomposed technique to model naturally ventilated barns by CFD	AU
PA16	A farm-specific simulation tool for energy needs estimation	CERTH
PA17	An integrated renewable energy system for the decarbonization of a laying hens farm	AUA
PA18	Renewable energy systems for the decarbonization of an experimental dairy cattle farm	ATB, LVAT
PA19	An integrated renewable energy system for the decarbonization of swine farms	UNIBO
PA20	An integrated renewable energy source (RES) system for the decarbonization of experimental swine farm	ILVO
PA21	Environmental and Economic Assessment of Renewable Energy Systems in an Experimental Laying Hens Farm	AUA
PA22	Environmental and Economic Assessment of Renewable Energy Systems in an Experimental Dairy Cattle Farm	AUA
PA23	Environmental and Economic Assessment of Integrated Renewable Energy Systems in a Commercial Swine Farm	AUA
PA24	Environmental and Economic Assessment of Renewable Energy Systems in an Experimental Swine Farm	AUA
PA25	Social Assessment of renewable technologies interventions in livestock facilities	CETRI
PA26	Innovative heat pumps for swine farm applications	PSYCTO, AUA
PA27	Innovative Photovoltaic-Thermal systems for dairy cattle farms	MG
PA28	Innovative Photovoltaic-Thermal Systems for Swine Farms	MG
PA29	Installation practices for Indoor/Outdoor Smart Control Systems in Livestock Buildings	PLEGMA
PA30	Geothermal potential for livestock farming applications in Europe	TERRA

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1 INTRODUCTION

The European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) was launched in 2012 to contribute to the European Union's strategy "Europe 2020" for smart, sustainable and inclusive growth. This strategy sets the strengthening of research and innovation as one of its five objectives and supports a new interactive approach to innovation: European Innovation Partnerships.

The resulting innovative knowledge and easily accessible end-user material from this project will feed into the CAP Network website (former EIP-AGRI website) for broad dissemination. The end-user material to be produced contains a substantial number of summaries for practitioners in the EIP common format ("Practice Abstracts"), including the characteristics of the project (e.g., contact details of partners, etc.).

Many Horizon 2020 multi-actor projects and thematic networks, as well as all EIP-AGRI Operational Groups, use this common format to provide farmers, foresters, advisers, practitioners, or whoever is interested with brief and concise practical information. The use of the EIP-AGRI common format facilitates not only the exchange of knowledge but also the contact between potential partners in innovation projects. It contributes to building up a unique repository of practical knowledge across the EU via the EIP-AGRI project database, which supports the dissemination of results of all interactive innovation projects.

A full package of practice abstracts has been produced by the RES4LIVE project, containing all the outcomes/recommendations which are ready for practice. The second set of practice abstracts will be soon listed and available on the dedicated CAP Network website page.

2 DESCRIPTION OF PRACTICE ABSTRACTS

2.1 PA11 - Adaptation of a diesel farm tractor for biomethane use

As part of RES4LIVE, a diesel farm tractor was retrofitted to use biomethane as a compressed natural gas (CNG) and thus completely replacing a fossil fuel source with a renewable fuel source. The conversion process consisted of replacing the fuel tank with a high-pressure storage system for biomethane, changing the combustion by removing the diesel pump and injectors to replace them by spark plugs, ignition coils, and gas injectors controlled by an electronic unit (ECU). In addition, the cylinder head and the pistons needed to be machined, and the turbocharger had to be checked to operate well with the new setup. The feasibility of the retrofit for older tractors depends on the expected remaining life time, which should be at least 15 years. An adequate setup of the converted engine will keep the previous power level and improve exhaust emissions depending on the previous engine stage, although not as to reach the latest standard (EU 2016/1628 Stage V). The operation of the converted tractor requires access to CNG, which could be provided on-farm if a biogas plant along with a biomethane upgrade plant and filling station is available, or from a nearby CNG filling station. For maintenance technical staff that is trained to work with gas-operated vehicles or machines is required.

2.2 PA12 - Borehole Thermal Energy Storage system for swine farm

Borehole thermal energy storage systems represent an effective solution to increase the energy efficiency of renewable energy plants. Still, they generally have to comply with strict regulatory frameworks, mainly due to the deliberate modification of the subsoil's natural state. RES4LIVE involved the design, installation testing, and monitoring of a borehole thermal energy storage (BTES) system able to exploit the excess solar heat from photovoltaic thermal collectors (PVT).

A specific procedure was developed to allow the balance between the underground solar thermal storage and the geothermal heat extraction, in a specific climatic and geological context, to achieve an almost 100% exploitation of renewable energy.

BTES implementation in a pilot farm
Characterization of the underground properties and analyses over, according to the following phases:
- investigation of geological, hydrogeological and geothermal conditions;
- numerical modeling of the flow and heat underground transport;
- Installation of test Borehole Heat Exchangers and dedicated piezometers;
- Thermal Response Test and quantification of the potential heat storage
- detailed design of the final system;
- system installation in the farm, commissioning and activation.

BTES performances
The data measured during one year of testing and monitoring of the installed system showed the following results in terms of performances of the geothermal heat storage:
Underground seasonal storage of 40% of solar thermal energy producible through PVT panels;
- Increase of COP of heat pump to heat a pig barn from 3 (air source mode) to 5 (geothermal source mode with BTES)
- Replacement of a 34 kW LPG boiler with a heat pump requiring only 9 kWel, which can be provided by the same PVT used to feed then BTES.
- Yearly emission reduction: 8621 kgCO2eq for a 840 m2 pig nursery barn.

2.3 PA13 - On-farm Biogas to Biomethane upgrading plant and filling station

Farms that have a biogas plant have the option to further upgrade the biogas to biomethane that can be stored as compressed natural gas (CNG) and afterwards can be used as a fossil-free alternative fuel for heavy duty vehicles like tractors or trucks.

The production of biogas on livestock farms is usually based on using field residues, manure and slurry, which all are renewable non-fossil resources. Commonly the raw biogas that originates from the anaerobic digestion of these resources is converted into thermal and electric energy in a combined heat and power plant (CHP). Plant sizes between 100kWel and 250kWel are economically feasible in practice. As an alternative, the raw biogas can be purified into biomethane and compressed to 250 bar for use as a BioCNG fuel.

The prototype biomethane upgrading plant utilized in RES4LIVE uses a single-stage membrane purification process with the return of the separated CO2 to the digester next to the CHP operation for electricity and heat production. Between 10 and 20 % of the total volume flow of raw biogas can be used for CNG fuel, because this results in a CH4 reduction in the remaining raw gas stream for the CHP - the gas is diluted, and if the methane content is too low, the engine in the CHP might not work properly any more. As an example, a biogas plant with 200 kWel as a basic situation corresponds to a raw biogas volume of 100 Nm3 per hour. Economic feasibility starts in the range of 10 to 35 Nm^3h^{-1} raw biogas that is purified into BioCNG fuel. For cost-saving purposes, the compressor used to push the biogas through the single-stage membrane separating CO2 and CH4 at the same time compresses the biomethane to a storage pressure of 250 bar. Drawing the CNG from the storage, the filling station works by pressure difference until pressure balance with the gas storage of the vehicle is achieved.

For the operation of a 35 m3h-1 raw biogas to BioCNG plant used at a capacity of 70 %, a full cost calculation results in fuel costs of 1.51 € kg-1 BioCNG. Any monetary benefits from GHG quotas from the production and use of biofuel have not yet been taken into account and can have an additional positive effect. This operating mode requires an adequate amount of consumers on-farm or also commercial or private consumers, which should be planned accordingly in a business model.

2.4 PA14 - Open barn ventilation system for a dairy cattle farm

Heat stress in dairy cows occurs more frequently in recent years as an effect of global warming, also in moderate climate zones. Cows can begin to be affected even by ambient temperatures lower than 18 °C. This is not just an issue of animal welfare, but also has an impact on productivity of the cows.

Usually dairy cows in these latitudes are housed in naturally ventilated barns. In summer conditions these barns often require support in air exchange, which can be achieved by various kinds of fans. An alternative can be a tube ventilation system. In such a tube ventilation system tubes are mounted above the rows of lying cubicles in the barn as well as above the walkway at the feeding table. Air from outside the barn is pressed into these tubes with ventilators. The tubes come with air outlet jets that provide fresh ambient air to the barn and can increase air flow rates in the barn.

The tube ventilation system can be enhanced with a cooling option. This is realized with evaporative cooling pads, one per tube, that allow cooling down ambient air that is then transported to a bypass box, where the pre-cooled air can be mixed with ambient air for some temperature regulation. In RES4LIVE temperature drops of up to 5 K could be measured as a result of the maximum pre-cooling level, acting as a proof of concept. The barn climate system operates based on data from environmental sensors in the barn, like temperature and humidity loggers or gas concentration sensors.

A computer simulation of the airflow dynamics in a given barn is required as a prerequisite and ensures that the tube ventilation and cooling system is dimensioned adequately. Since the additional energy demand of this ventilation system (as other ventilation systems) is seasonal with peak demand during summer, these systems synergize very well with photovoltaic systems that provide their peak power in the same conditions where barn ventilation is required.

2.5 PA15 - Domain decomposed technique to model naturally ventilated barns by CFD

Computational Fluid Dynamics (CFD) is a promising technique to simultaneously obtain the fields of velocity, concentration, temperature, pressure and humidity ratio in livestock production barns over the entire computational domain, compared to field on-site measurements with limited measuring points. Although the distinct advantage of CFD modelling, one of challenges lies in the high requirement of computational compacity for large-scale livestock production buildings when the computational domain is wholly simulated with all geometrical detailed in the barns. This has limited the application of CFD modelling in study on sustainability and mitigation of heat stress and gaseous emissions from livestock buildings. Without proper prediction of those parameters, especially under the pressure of climate change, large uncertainties exist in assessment of the microclimate surrounding animals, which is highly related to the animal welfare and productivity, after new techniques are implemented for adaptive climatic barns.

In this context, we strive to predict the air speed, temperature and relative humidity around animals by adopting a domain decomposed technique to model the naturally ventilated barns by CFD in RES4LIVE project. As shown in the figure, the computational domain is decomposed into two domains, (1) the atmosphere domain plus the animal housing domain without detailed information inside the animal housing, and (2) the domain of animal housing with detailed information of housing configuration and animals. The parameters such as velocity, temperature, pressure etc. at openings of the animal housing achieved from modelling of domain (1) are used as boundary conditions for modelling of domain (2). This approach allows us to conduct CFD simulations with durable computational capacity and reasonable accuracy in predicting the velocity, temperature, humidity ratio surrounding animals. Thus, the technologies in preventing and alleviating heat stress, e.g., tube ventilation augmented with mechanical cooling developed within the context of RES4LIVE, can be evaluated with reasonable accuracy.

2.6 PA16 - A farm-specific simulation tool for energy needs estimation

Energy modelling of livestock houses has significantly advanced in recent years as enables a precise assessment of the energy consumption due to climate control systems, a major energy consumer in these facilities.

The developed simulation framework is designed to simulate the most relevant phenomena occurring inside livestock house:

- Initialization module
- Animal simulation module
- Thermal balance module
- Cooling ventilation module
- Moisture balance module

In order to initiate the simulation input data from the user are required, including:

the geometrical

and

thermophysical properties, farming features, specifications of the climate control system, and outdoor weather conditions.

AUA, ILVO and Golinelli farm

An increasing number of customized energy models has been developed by implementing the simple hourly method of ISO 13790, based on the thermal–electrical analogy between the simulated livestock house and an equivalent electrical network with 5 resistance and 1 capacitance (5R1C). This method applied separately to the farms of our interest.

The AUA farm: The building and its climate control system underwent extensive renovation as part of the RES4LIVE Project. At this farm the above method applied as described corresponding to the above overall thermal profile.

The ILVO farm: Pig production on this farm is carried out with a closed cycle the focus of the modelling activity in one of the fattening compartments. Below are the corresponding results.

The Golinelli farm: It operates a closed-cycle pig production system, managing all the stages. The nursery barn is partitioned into three different thermal zones corresponding to a multi-zone calculation described below.

2.7 PA17 - An integrated renewable energy system for the decarbonization of a laying hens farm

Intensive livestock farming significantly contributes to greenhouse gas emissions due to its reliance on fossil fuels, especially for maintaining optimal conditions in livestock buildings. The transition to Renewable Energy Sources (RES) is essential for reducing the environmental impact of the EU's livestock sector. Our recent initiative aimed to decarbonize experimental laying hen facilities while enhancing animal welfare by integrating a RES system.

The farm was upgraded with an innovative heat pump (HP) for climate control and a solar photovoltaic (PV) system for power generation. A sensor-based monitoring system was implemented to collect data on the system's performance and indoor conditions over an extended period, focusing on both summer and winter seasons.

Preliminary results are promising. The installed HP effectively maintains adequate indoor air temperatures during heat waves, eliminating mortality and thereby improving animal welfare. Additionally, when paired with the PV system, it reduces electricity consumption from the grid by 20-23%. This reduction leads to significant CO_2-eq savings, with approximately 688 kgCO_2-eq in summer and 314 kgCO_2-eq in winter.

During the testing and fine-tuning period, the HP achieved a Seasonal Coefficient of Performance of 2.42 in summer and 3.65 in winter. These findings underscore the potential for scaling up RES integration in commercial livestock facilities, demonstrating substantial benefits for both energy efficiency and animal welfare.

This project provides valuable insights for practitioners seeking to adopt sustainable practices in livestock farming, highlighting the feasibility and advantages of incorporating RES technologies.

2.8 PA18 - Renewable energy systems for the decarbonization of an experimental dairy cattle farm

For the defossilization of an experimental dairy cattle farm, renewable energy systems (RES) were combined to provide electrical power for various devices as well as to replace diesel-powered machines with ones that can use biomethane instead.
The RES on this farm include a biomethane upgrade plant, a former diesel tractor that was converted to run on compressed natural gas (CNG), a sensor-operated tube ventilation and cooling system for a dairy barn, and a set of photovoltaic thermal (PVT) panels with a heat storage tank.

The base for this was an existing biogas plant with a combined heat and power plant (CHP) that is already able to provide the farm with electrical power and sells excess electricity to the national grid. In addition, the CHP provides thermal energy for heating the farm's office buildings. The biogas plant is fed with the slurry of the dairy cattle on the farm, and the dairy cows are housed in naturally ventilated barns. Since heat stress has become an issue in dairy cows increasingly, the barn was equipped with a combined tube ventilation and cooling system that operates sensor-based and detects climate conditions that lead to heat stress. Based on environmental sensors that track temperature, relative humidity, and gas concentrations in the barn, the natural ventilation of the barn is supported by injecting ambient air from outside the barn through ventilation tubes with exhaust nozzles above the lying cubicles and the feed table as soon as a first temperature threshold is exceeded. When the temperature rises further, additional ambient air can be pre-cooled in evaporative cooling pads and mixed into the ventilation airflow to drop the air outlet temperatures and mitigate heat stress conditions in the barn. The heat stress situations naturally are more prominent in the warmer half of the year, which allows the use of a PVT system as a synergy. The solar panels provide extra electricity at the time when it is needed for the barn climate system. In addition, the PVT system provides thermal energy that can be used to partly replace the boiler that supplies hot water that is regularly used e.g. for cleaning milking equipment.

The farm tractor that is regularly used to feed the dairy cattle had its diesel engine converted to now use CNG. The conversion process kept the tractor's power level and improved the emission level. The CNG is provided by the biomethane upgrade plant that uses a single membrane and a dual-purpose compressor to concentrate the biogas to a methane content of at least 95 % and store the then-compressed gas at a pressure of 250 bar. The prototype scale plant already produces more than enough CNG to run a tractor.

Integrated RES systems at the LVAT dairy cow farm

A PVT system with a solar station providing an average electrical energy of 4.50 MWh per year and an average thermal energy of 24.75 MWh

Thermal energy short term storage tank with 1,500 L capacity

Prototype off-grid BioCNG upgrade plant with a capacity to produce up to 10 Nm^3 h-1 CNG with at least 95 % methane content at a storage pressure of 250 bar, with on-farm filling station

A diesel farm tractor converted to use CNG from renewable sources

Sensor-controlled tube ventilation and cooling system for a dairy barn

2.9 PA19 - An integrated renewable energy system for the decarbonization of swine farms

A sustainable heating system was developed for pig barns as an alternative to fossil-fuel-based ones. It consists specifically in an integrated Renewable Energy Source (RES) system incorporating a borehole thermal energy storage (BTES) and photovoltaic thermal (PVT) collectors, integrated with a Dual-Source Heat Pump (DSHP). A sophisticated control system was developed and implemented to monitor energy usage and environmental conditions. The results of pilot installation and experimental trials showed that a tailored mix of RES can be effectively established for a given livestock farm, leveraging the renewable resources prevalent in farming environments.

The heating load provided by the geothermal heat pump can rise the temperature of the radiant pipes up to 55°C, i.e. the operating temperature targeted with the previous fossil-based plant. The fundamental system architecture incorporates a dual-source heat pump featuring not only an air-cooled evaporator but also a heat exchanger for transferring heat with a water/glycol blend sourced from a sequence of PVT collectors connected to boreholes. The primary novelty of the system resides in its capability for hybrid operation, enabling simultaneous utilization of both ground-sourced and air-sourced heat, resulting in increased heating capacity and COP efficiency.

Integrated RES system

- 35 kW medium temperature heat pump;
- A PVT system with a solar station, to provide electricity for the heat pump operation and the electric needs of the nursery barn with its 8 kWel electrical output, as well as thermal energy with its thermal output of 25 kWth;
- Borehole Thermal Energy Storage (BTES) system that exploits both solar thermal energy and underground heat capacity to increase the heat pump efficiency by storing the excess heat from PVT;
- Smart control system.

2.10 PA20 - An integrated renewable energy source (RES) system for the decarbonization of experimental swine farm

An integrated renewable energy system (RES) was designed and implemented for an experimental swine farm as a sustainable alternative to the fossil-fuel-based heating system. The RES setup includes 24 photovoltaic thermal (PVT) collectors, two modular heat pumps, and a thermal energy storage tank. The control system monitors the heat energy supply, while a network of sensors tracks environmental conditions. Monitoring and evaluation results highlight the system's efficiency and effectiveness in replacing the farm's fossil fuel-based gas boilers, demonstrating the viability of this renewable solution for meeting the farm's heating needs.

The farm's heating requirements include air heating for the fattening pig compartments, floor heating for the farrowing compartments, and a combination of air and floor heating for the weaned piglet compartments. The entire heating demand is met year-round by the integrated renewable energy system (RES). Previously, a fossil-fuel gas boiler was used to heat circulating water to 70 °C for these needs. Now, two modular heat pumps have been installed: a high-temperature pump that heats the water to 62 °C and a low-temperature pump that heats it to 42°C. Additionally, the RES system offers a hybrid operation feature, allowing it to simultaneously utilize heat from both PVT panels and air sources, which enhances heating capacity and improves the system's coefficient of performance.

Integrated RES system at ILVO swine farm

- A PVT system with a solar station unit to generate 8.4 kWel electrical energy, and 32.8 kWth thermal energy.
- Thermal energy storage tank that stores the thermal energy from the PVT that is used to increase the heat pump coefficient of performance.
- Two modular heat pumps
    - 24.5 kW medium temperature
    - 39.5 kW high temperature
- Smart control and sensor system.

2.11 PA21 - Environmental and Economic Assessment of Renewable Energy Systems in an Experimental Laying Hens Farm

Integrating renewable energy systems (RES) could play a crucial role in enhancing the sustainability of livestock farming practices. A study conducted on a small experimental egg-laying hen farm in Greece assessed the animal welfare and productivity performance of such a system in comparison to the one before implementing RES, highlighting the potential benefits for poultry farmers from available funding to support its adoption.

The system implemented includes:

- A 9 kWp photovoltaic (PV) system to supply part of the farm's energy needs
- A 10 kW water-to-air heat pump for heating, cooling, and dehumidifying the indoor air
- An LED lighting system tailored to the hens' specific requirements
- A smart control system, incorporating both environmental sensors and energy meters

Prior to the RES4LIVE project, the farm's relatively simple and outdated system consumed low amounts of energy. While the new system is more energy-intensive, it significantly improves the thermal comfort of the hens by regulating indoor air quality, temperature, and humidity compared to the previous setup. This leads to enhanced animal welfare, increased productivity, and lower mortality rates.

SYSTEM	PERFORMANCE PARAMETERS	
Heat pump	$SCOP_{Cooling}$	$SCOP_{Heating}$
	3.12	3.77
Photovoltaics	Conversion efficiency	
	10.4%	
	Self-Sufficiency (%)	Self-Consumption (%)
	22.81	84.12
Animal welfare and productivity	Decrease in mortality rate	
	28%	
	Increase in total egg production	Increase in average production per animal
	10%	19%

Although there is still much work to be done, adopting similar systems on poultry farms across Greece could improve animal welfare and productivity, with good potential of also improving their environmental and economic sustainability.

2.12 PA22 - Environmental and Economic Assessment of Renewable Energy Systems in an Experimental Dairy Cattle Farm

Integrating renewable energy sources (RES) systems into farming practices can greatly enhance operational efficiency and sustainability. This assessment examines the environmental and economic impacts of two innovative systems implemented on an experimental dairy cattle farm in Germany. The results suggest that cattle farmers can leverage these benefits and take advantage of available funding opportunities to support implementation.

The two systems evaluated are:

- A biogas-to-biomethane upgrading plant, equipped with a BioCNG filling station
- An adapted farm tractor for BioCNG use

The operation of the biogas-to-biomethane upgrading plant leads to remarkable diesel savings, causing a beneficial environmental effect equivalent to 4.6 times the total environmental burden of the biomethane supply chain system, only from the on-farm biomethane use in the retrofitted tractor. If all diesel savings are considered, including a potential sale of surplus BioCNG, the corresponding beneficial environmental effect could be increased up to 13 times.

The adapted tractor running on BioCNG offers additional environmental benefits compared to a conventional diesel tractor, reducing overall environmental burden by 9%, and the overall environmental burden caused by non-renewable fossil fuels and water consumption by 2 and 3 times, respectively.

From an economic standpoint, considering both the sale of BioCNG and fuel savings, the discounted payback period (DPBP) for the biogas-to-biomethane upgrading plant is 10 years. With subsidies covering 20% to 40% of the total investment costs, aimed at promoting decarbonization at the EU level, the DPBP could be shortened to around 8 to 5 years, respectively. After that, the DPBP for the adapted tractor would be around 2 years.

Incorporating similar interventions could improve the environmental and economic sustainability of cattle farms producing biogas in Germany.

2.13 PA23 - Environmental and Economic Assessment of Integrated Renewable Energy Systems in a Commercial Swine Farm

Adopting renewable energy systems (RES) can play a key role in improving the sustainability of farming practices. A study on a commercial swine farm in Italy evaluated the environmental and economic impacts of such a system in comparison to the system before installing RES, highlighting how swine farmers could benefit from available funding to support its implementation.

The system used includes:

- A 7.68 kWel - 25 kWth photovoltaic-thermal (PVT) system
- A multisource heat pump (35 kW)
- A 30m borehole thermal energy storage system
- A smart control system

When compared to the LPG boiler used before the project for heating the nursery barn of this farm, the RES4LIVE system could reduce the overall environmental burdens by 4%. This includes reducing the overall environmental burden caused by photochemical ozone formation (15%), non-renewable fossil resource consumption (15%), cancer-related human toxicity (13%), and climate change impact category (6%).

Economically, with EU subsidies covering either 20% or 40% of the total investment costs to support decarbonization, the discounted payback period for this system could range from 21-22 years in the former case, to 13-14 years in the latter.

Implementing similar systems on swine farms in Italy could improve both environmental and financial sustainability.

2.14 PA24 - Environmental and Economic Assessment of Integrated Renewable Energy Systems in an Experimental Swine Farm

In the pursuit of sustainable farming practices, integrating renewable energy systems can significantly improve operational efficiency. The environmental and economic impacts of an integrated system on an experimental swine farm in Belgium are assessed, suggesting that swine farmers could capitalize on potential benefits and utilize available funding opportunities to support implementation.

The system includes:

- 24 photovoltaic-thermal (PVT) collectors
- Two multisource heat pumps, high-temperature (40 kW) and low-temperature (25 kW), equipped with a short-term heat storage tank
- A smart control system

Compared to the existing system—a natural gas boiler for space heating and domestic hot water—the integration of the RES4LIVE system has the potential to reduce overall environmental burdens by 12%. Specifically, it can reduce the overall environmental burden caused by (i) ozone depletion by 19%, (ii) non-renewable fossil resource consumption by 17%, and (ii) the climate change impact category by 15%.

At the economic level, and considering subsidies ranging from 20% to 40% of the total investment cost, as a means to promote decarbonization at the EU level, the integrated renewable energy system can achieve a discounted payback period of approximately 13-14 years and 9-10 years, respectively.

Therefore, by incorporating similar interventions, swine farms in Belgium could enhance both their environmental and economic sustainability.

2.15 PA25 - Social Assessment of renewable technologies interventions in livestock facilities

The goal of the Social Assessment (SA) was to evaluate the social impacts of deploying Renewable Energy Systems (RES) technologies in livestock operations across the four pilot farms involved in the RES4LIVE project. The SA is critical for assessing potential energy upgrades in livestock farms, as it offers a comprehensive understanding of the project's social effects on various stakeholders. This ensures that the benefits go beyond cost savings and environmental protection to include improved social outcomes, increased community acceptance, and greater sustainability.

The social assessment indicated that the overall SA Index remained positive across all scenarios and analyses.

Results from all farms showed that most participants had a generally quite positive perception of the farm's transparency in operations and reporting, particularly with regard to energy efficiency and emissions reduction. The most notable positive social impacts were observed in areas such as Environmental and Ethical considerations, Health and Safety, Human Rights, and Governance.

However, many workers reported no significant improvements in wages or compensation during the project interventions, despite an increase in workload and/or working hours due to the RES initiatives. Areas for improvement include providing more comprehensive training for farm personnel on the operation of new RES technologies to ensure the smooth running of farm operations. Additionally, efforts should be made to reduce disruptions during and after the installation of the systems.

This social impact analysis highlighted the positive effects of the RES4LIVE technologies and provided valuable insights, showing that future implementations of RES technologies can be better aligned with stakeholder expectations and lead to even more positive social outcomes.

2.16 PA26 - Innovative heat pumps for swine farm applications

Transitioning to Renewable Energy Sources (RES) is vital for reducing the EU's livestock sector's environmental impact. Our initiative aims to decarbonize heating in European swine farms by integrating innovative dual-source heat pumps (DSHPs). These DSHPs are designed to replace traditional boilers for space heating and domestic hot water.

At a farrow-to-finish pig farm, two DSHPs replaced a 60 kW gas condensing boiler. The low-temperature (25 kW) provides floor heating at 42°C, while the high-temperature (40 kW) handles air heating and domestic hot water at 60°C. Combined with a photovoltaic thermal (PVT) system and a short-term thermal energy storage tank, the HPs achieve a higher Coefficient of Performance (COP). A dry cooler supplements the system when solar energy is inadequate. The system operated 85% in air-water mode and 15% in water-water mode, with average COPs were 2.95 for the high-temperature HP and 4.87 for the low-temperature HP in air-water mode, and 9.85 and 4.10, respectively, in water-water mode.

In a second pilot farm, a multi-source HP replaced a 34 kW LPG boiler for the nursery barn's heating system. Here, PVT collectors are linked to a borehole thermal energy storage system, facilitating long-term heat storage. The HP utilized ambient heat via dry cooler. The HP maintained hallway temperatures near the setpoint, operating 17.4% of the time. It delivered 75% of its heat in ground mode and 25% in hybrid mode, with no air mode activation. The average COPs were 4.67 (ground), 3.50 (hybrid), and 4.34 (overall). This project offers valuable insights for practitioners seeking to adopt sustainable practices in livestock farming, demonstrating the feasibility and benefits of integrating RES technologies.

2.17 PA27 - Innovative Photovoltaic-Thermal systems for dairy cattle farms

Intensive livestock farming consumes a considerable amount of thermal and electrical energy, especially in dairy farms where hot water is needed for cleaning the milk tanks, barn, and disinfection of the milking machines. Therefore, Photovoltaic thermal (PVT) collectors, that convert solar radiation into usable thermal and electrical energy are a promising form of renewable energy generation for agriculture and livestock farming specifically. A heat storage tank can be used to store excess heat during the day for use at night.

In dairy farms with milk storage, heat can be recovered from the milk chillers to pre-heat any water for domestic hot water use. It was decided to use high performing PVT collectors to further heat up the pre-heated water to the desired 60°C for hot water use in the farm.

LVAT Dairy Farm PVT Installation Highlights

- 24 Solarus concentrating PVT collectors (55 m2) were installed to take heat from the heat recovery system and further heat the water to the desired domestic hot water temperature for the farm.
- Expected annual solar heat supply to the farm of 7.5 MWh with 24 Solarus PVT collectors.
- Expected annual electric PV supply to the farm of 4 MWh with 24 Solarus PVT collectors.
- Annual maintenance costs are less than 500 EUR.
- With the heat recovery system and PVT installation, the e-boiler for domestic hot water is only expected to run during the winter for top up of heat.
- Expected return on investment is less than 8 years, which can be reduced with increasing gas and electricity prices as well as increasing price volatility.

2.18 PA28 - Innovative Photovoltaic-Thermal Systems for Swine Farms

Intensive livestock farming consumes a considerable amount of thermal and electrical energy, especially in swine farms where piglets need heating all year round. Therefore, Photovoltaic thermal (PVT) collectors, that convert solar radiation into usable thermal (for hot water and space heating) and electrical energy are a promising form of renewable energy generation for agriculture and livestock farming specifically. A heat storage tank can be used to store excess heat during the day for use at night. To have available heat all year round, the PVTs can supply heat to a heat pump and thereby increasing the efficiency of the heat pump by up to two times. This was the case in the ILVO pilot farm in Belgium. PVT collectors can also be combined with a geothermal seasonal heat storage system to store excess heat during the summer for the winter. This is case in the Golinelli swine farm in Emilia-Romagna, Italy.

ILVO Swine Farm PVT System with Heat Pump Highlights

- 24 Abora aH72 PVT collectors (45m2) were installed in combination with 2 heat pumps that deliver the final space and domestic hot water heat to the farm.
- Expected annual solar heat supply to the farm of 15 MWh to 21 MWh with 24 Abora aH72 PVT collectors.
- Expected annual electric PV supply to the farm of 4 MWh with 24 Abora aH72 PVT collectors.
- Annual maintenance costs are less than 500 EUR.
- With the heat pump and PVT installation, no gas is expected to be consumed by the farm all year round.
- Expected return on investment is less than 8 years, which can be reduced with increasing gas and electricity prices as well as increasing price volatility.

Golinelli Swine Farm PVT System with Geothermal Storage and Heat Pump Highlights

- 24 Samster uninsulated PVT collectors (45m2) were installed in combination with a seasonal geothermal storage and heat pump to deliver the final space and domestic hot water heat to the farm.
- Expected annual solar heat supply to the farm of 19 MWh to 25 MWh with 24 Samster PVT collectors.
- Expected annual electric PV supply to the farm of 10 MWh with 24 Samster PVT collectors.
- Annual maintenance costs are less than 300 EUR.

With the heat pump and PVT installation, no fossil fuels are expected to be consumed by the farm all year round.

Expected return on investment is less than 6 years, which can be reduced with increasing gas and electricity prices as well as increasing price volatility.

2.19 PA29 - Installation practices for Indoor/Outdoor Smart Control Systems in Livestock Buildings

Smart control systems for livestock buildings offer a transformative solution for farmers seeking to improve the efficiency, welfare, and sustainability of their operations. Our work focuses on best practices for the installation of both indoor and outdoor systems that monitor and control vital elements such as temperature, humidity, lighting, and air quality in livestock environments.

By implementing these systems, farmers can reduce energy costs, enhance livestock welfare, and increase overall productivity. Automated controls allow for precise adjustments in real-time, ensuring optimal living conditions for livestock without requiring constant manual oversight. For example, the smart control system can automatically adjust ventilation based on humidity levels, reducing the risk of disease.

From a cost-benefit perspective, the initial investment in smart control systems is offset by long-term savings in energy consumption, reduced labor, and fewer losses due to health-related issues. Additionally, data generated from these systems helps farmers make informed decisions about resource allocation, animal health, and operational efficiency.

Farmers adopting these smart technologies are better equipped to meet industry demands, reduce costs, and improve the welfare of their livestock, leading to a more sustainable and profitable future.

Smart control installation highlights in RES4LIVE

- 4 pilot farms (Belgium, Germany, Greece, Italy)
- 2 Swine farms, 1 Poultry farm, 1 Dairy farm
- Environmental sensors (Weather stations, Temperature, Humidity, CO2, NH3, H2S, O2, VOC)
- Energy consumption sensors
- Integration with various systems (Heat Pump, PVT, Ventilation, Anemometers, Biogas)
- Automation (Heat Pumps, Ventilation)
- Alerts though a notification system

2.20 PA30 - Geothermal potential for livestock farming applications in Europe

The use of renewable energy sources can ensure that the cost of barn climatization can remain low. Geothermal energy can certainly be an alternative here. Moreover, shallow geothermal energy can play an important role in maintaining summer comfort. Borehole thermal energy storage (BTES) uses vertical loops to exchange thermal energy. Aquifer thermal energy storage (ATES) systems use wells with extraction and injection of groundwater. It is prohibitively expensive to deploy classical compression cooling for this purpose. Geothermal energy offers opportunities to use passive cooling to also prevent overheating with minimal energy costs. As an alternative, smart active cooling with geothermal reversable heat pumps offers a solution to increase animal comfort and productivity up to an optimal level.

Geothermal energy concept for Pig Farm in Belgium

The research site of ILVO in Belgium (the Pig Farm) suits best for the integration of a central geothermal system with BTES. The barn is relatively young (recently built) and equipped with modern HVAC installations, consisting of radiant panels (twin tubes), floor heating combined with an extensive ventilation system. This installation can be relatively well adapted to integrate barn cooling.

The geothermal system provides the necessary cold after a winter in which heating is mainly required. This cold is produced, without using compression cooling, purely by circulation through the ground and is therefore very efficient. In this project, passive cooling via twin tubes fitted in the air ducts can provide limited cooling capacity. Integrating smart use of the heat pumps, which provide year-round heat for piglet heating and hot tap water, allows active cooling by bringing the residual product of the heating into the stables as cooling during summer.

When calculating total cost of ownership over 30 years, the dynamic payback time will be 10 years. Over the lifespan of the installation, a cost saving of 234,5 k€ can be achieved (-37%).

ANNEX – 2ND BASTCH OF PRACTICE ABSTRACTS UPLOADED ON RES4LIVE WEBSITE

Practice Abstract n. 11

RES4LIVE
ENERGY SMART LIVESTOCK FARMING TOWARDS ZERO FOSSIL FUEL CONSUMPTION

eip-agri
AGRICULTURE & INNOVATION

Adaption of a diesel farm tractor for biomethane use

As part of RES4LIVE, a diesel farm tractor was retrofitted to use biomethane as a compressed natural gas (CNG) and thus completely replacing a fossil fuel source with a renewable fuel source. The conversion process consisted of replacing the fuel tank with a high-pressure storage system for biomethane, changing the combustion by removing the diesel pump and injectors to replace them by spark plugs, ignition coils, and gas injectors controlled by an electronic unit (ECU). In addition, the cylinder head and the pistons needed to be machined, and the turbocharger had to be checked to operate well with the new setup. The feasibility of the retrofit for older tractors depends on the expected remaining life time, which should be at least 15 years. An adequate setup of the converted engine will keep the previous power level and improve exhaust emissions depending on the previous engine stage, although not as to reach the latest standard (EU 2016/1628 Stage V). The operation of the converted tractor requires access to CNG, which could be provided on-farm if a biogas plant along with a biomethane upgrade plant and filling station is available, or from a nearby CNG filling station. For maintenance technical staff that is trained to work with gas-operated vehicles or machines is required.

Gas tanks on the tractor and gas pressure regulation system

Modified cylinder head and spark plug position

The tractor before the conversion (left) and after the conversion next to the CNG upgrade and filling station (right)

The RES4LIVE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement No 101000785.

Practice Abstract n. 12

RES4LIVE
ENERGY SMART LIVESTOCK FARMING TOWARDS ZERO FOSSIL FUEL CONSUMPTION

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AGRICULTURE & INNOVATION

Borehole Thermal Energy Storage system for swine farm

Borehole thermal energy storage systems represent an effective solution to increase the energy efficiency of renewable energy plants. Still, they generally have to comply with strict regulatory frameworks, mainly due to the deliberate modification of the subsoil's natural state. RES4LIVE involved the design, installation testing, and monitoring of a borehole thermal energy storage (BTES) system able to exploit the excess solar heat from photovoltaic thermal collectors (PVT).

A specific procedure was developed to allow the balance between the underground solar thermal storage and the geothermal heat extraction, in a specific climatic and geological context, to achieve an almost 100% exploitation of renewable energy.

The RES4LIVE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement No 101000785.

On-farm biogas to biomethane upgrading plant and filling station

Farms that have a biogas plant have the option to further upgrade the biogas to biomethane that can be stored as compressed natural gas (CNG) and afterwards can be used as a fossil-free alternative fuel for heavy duty vehicles like tractors or trucks.

The production of biogas on livestock farms is usually based on using field residues, manure and slurry, which all are renewable non-fossil resources. Commonly the raw biogas that originates from the anaerobic digestion of these resources is converted into thermal and electric energy in a combined heat and power plant (CHP). Plant sizes between 100kW$_{el}$ and 250kW$_{el}$ are economically feasible in practice. As an alternative, the raw biogas can be purified into biomethane and compressed to 250 bar for use as a BioCNG fuel.

The prototype biomethane upgrading plant utilized in RES4LIVE uses a single-stage membrane purification process with the return of the separated CO_2 to the digester next to the CHP operation for electricity and heat production. Between 10 and 20 % of the total volume flow of raw biogas can be used for CNG fuel, because this results in a CH_4 reduction in the remaining raw gas stream for the CHP - the gas is diluted, and if the methane content is too low, the engine in the CHP might not work properly any more. As an example, a biogas plant with 200 kW$_{el}$ as a basic situation corresponds to a raw biogas volume of 100 Nm^3 per hour. Economic feasibility starts in the range of 10 to 35 Nm^{3}h^{-1} raw biogas that is purified into BioCNG fuel. For cost-saving purposes, the compressor used to push the biogas through the single-stage membrane separating CO_2 and CH_4 at the same time compresses the biomethane to a storage pressure of 250 bar. Drawing the CNG from the storage, the filling station works by pressure difference until pressure balance with the gas storage of the vehicle is achieved.

For the operation of a 35 m^{3}h^{-1} raw biogas to BioCNG plant used at a capacity of 70 %, a full cost calculation results in fuel costs of 1.51 € kg^{-1} BioCNG. Any monetary benefits from GHG quotas from the production and use of biofuel have not yet been taken into account and can have an additional positive effect. This operating mode requires an adequate amount of consumers on-farm or also commercial or private consumers, which should be planned accordingly in a business model.

BioCNG upgrade plant and fillig station (left), filling up a CNG tractor (right)

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RES4LIVE
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eip-agri AGRICULTURE & INNOVATION

Open barn ventilation system for a dairy cattle farm

Heat stress in dairy cows occurs more frequently in recent years as an effect of global warming, also in moderate climate zones. Cows can begin to be affected even by ambient temperatures lower than 18 °C. This is not just an issue of animal welfare, but also has an impact on productivity of the cows.

Usually dairy cows in these latitudes are housed in naturally ventilated barns. In summer conditions these barns often require support in air exchange, which can be achieved by various kinds of fans. An alternative can be a tube ventilation system. In such a tube ventilation system tubes are mounted above the rows of lying cubicles in the barn as well as above the walkway at the feeding table. Air from outside the barn is pressed into these tubes with ventilators. The tubes come with air outlet jets that provide fresh ambient air to the barn and can increase air flow rates in the barn.

The tube ventilation system can be enhanced with a cooling option. This is realized with evaporative cooling pads, one per tube, that allow cooling down ambient air that is then transported to a bypass box, where the pre-cooled air can be mixed with ambient air for some temperature regulation. In RES4LIVE temperature drops of up to 5 K could be measured as a result of the maximum pre-cooling level, acting as a proof of concept. The barn climate system operates based on data from environmental sensors in the barn, like temperature and humidity loggers or gas concentration sensors.

A computer simulation of the airflow dynamics in a given barn is required as a prerequisite and ensures that the tube ventilation and cooling system is dimensioned adequately. Since the additional energy demand of this ventilation system (as other ventilation systems) is seasonal with peak demand during summer, these systems synergize very well with photovoltaic systems that provide their peak power in the same conditions where barn ventilation is required.

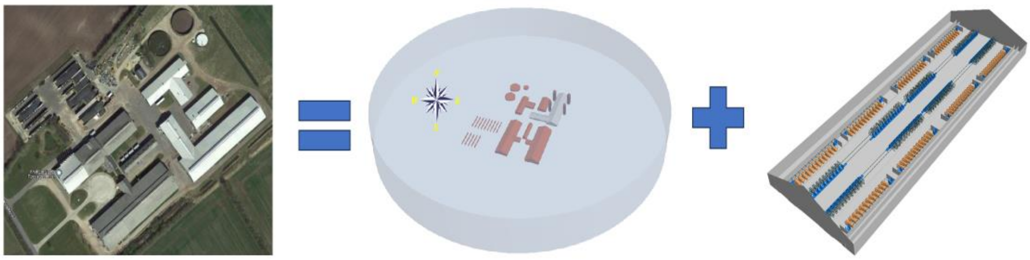
Evaporative cooling pads (above)

Ventilation and cooling tube with air outlet jets above a row of lying cubicles (right)

The RES4LIVE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement No 101000785.

Domain decomposed technique to model naturally ventilated barns by CFD

Computational Fluid Dynamics (CFD) is a promising technique to simultaneously obtain the fields of velocity, concentration, temperature, pressure and humidity ratio in livestock production barns over the entire computational domain, compared to field on-site measurements with limited measuring points. Although the distinct advantage of CFD modelling, one of challenges lies in the high requirement of computational compacity for large-scale livestock production buildings when the computational domain is wholly simulated with all geometrical detailed in the barns. This has limited the application of CFD modelling in study on sustainability and mitigation of heat stress and gaseous emissions from livestock buildings. Without proper prediction of those parameters, especially under the pressure of climate change, large uncertainties exist in assessment of the microclimate surrounding animals, which is highly related to the animal welfare and productivity, after new techniques are implemented for adaptive climatic barns.



In this context, we strive to predict the air speed, temperature and relative humidity around animals by adopting a domain decomposed technique to model the naturally ventilated barns by CFD in RES4LIVE project. As shown in the figure, the computational domain is decomposed into two domains, (1) the atmosphere domain plus the animal housing domain without detailed information inside the animal housing, and (2) the domain of animal housing with detailed information of housing configuration and animals. The parameters such as velocity, temperature, pressure etc. at openings of the animal housing achieved from modelling of domain (1) are used as boundary conditions for modelling of domain (2). This approach allows us to conduct CFD simulations with durable computational capacity and reasonable accuracy in predicting the velocity, temperature, humidity ratio surrounding animals. Thus, the technologies in preventing and alleviating heat stress, e.g., tube ventilation augmented with mechanical cooling developed within the context of RES4LIVE, can be evaluated with reasonable accuracy.

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RES4LIVE
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eip-agri AGRICULTURE & INNOVATION

A farm-specific simulation tool for energy needs estimation

Energy modelling of livestock houses has significantly advanced in recent years as enables a precise assessment of the energy consumption due to climate control systems, a major energy consumer in these facilities.

The developed simulation framework is designed to simulate the most relevant phenomena occurring inside livestock house:

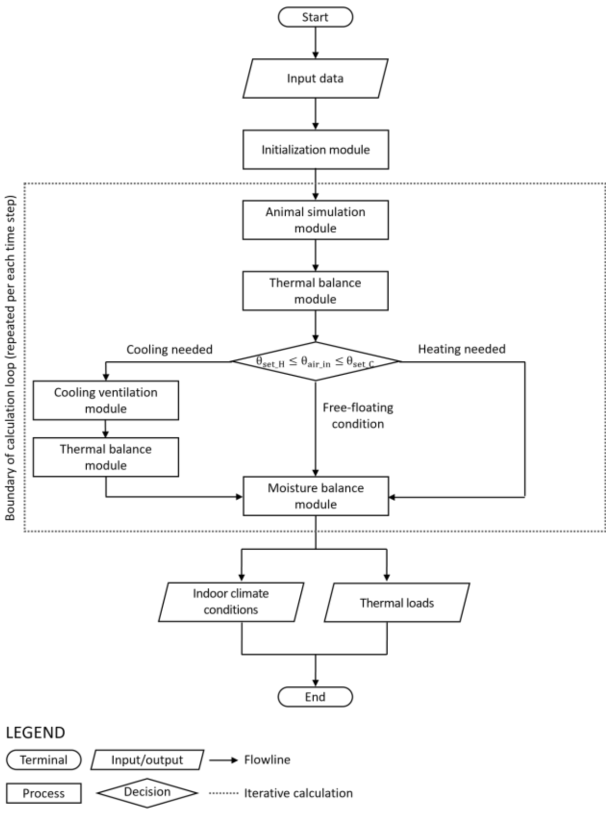
- Initialization module
- Animal simulation module
- Thermal balance module
- Cooling ventilation module
- Moisture balance module

In order to initiate the simulation input data from the user are required, including:

- the geometrical

and

- thermophysical properties, farming features, specifications of the climate control system, and outdoor weather conditions.



AUA, ILVO and Golinelli farm

An increasing number of customized energy models has been developed by implementing the simple hourly method of ISO 13790, based on the thermal–electrical analogy between the simulated livestock house and an equivalent electrical network with 5 resistance and 1 capacitance (5R1C). This method applied separately to the farms of our interest.

- **The AUA farm**: The building and its climate control system underwent extensive renovation as part of the RES4LIVE Project. At this farm the above method applied as described corresponding to the above overall thermal profile.

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Practice Abstract n. 17

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AGRICULTURE & INNOVATION

An integrated renewable energy system for the decarbonization of a laying hens farm

Intensive livestock farming significantly contributes to greenhouse gas emissions due to its reliance on fossil fuels, especially for maintaining optimal conditions in livestock buildings. The transition to Renewable Energy Sources (RES) is essential for reducing the environmental impact of the EU's livestock sector. Our recent initiative aimed to decarbonize experimental laying hen facilities while enhancing animal welfare by integrating a RES system.

The farm was upgraded with an innovative heat pump (HP) for climate control and a solar photovoltaic (PV) system for power generation. A sensor-based monitoring system was implemented to collect data on the system's performance and indoor conditions over an extended period, focusing on both summer and winter seasons.

Preliminary results are promising. The installed HP effectively maintains adequate indoor air temperatures during heat waves, eliminating mortality and thereby improving animal welfare. Additionally, when paired with the PV system, it reduces electricity consumption from the grid by 20-23%. This reduction leads to significant CO2-eq savings, with approximately 688 kgCO2-eq in summer and 314 kgCO2-eq in winter.

During the testing and fine-tuning period, the HP achieved a Seasonal Coefficient of Performance of 2.42 in summer and 3.65 in winter. These findings underscore the potential for scaling up RES integration in commercial livestock facilities, demonstrating substantial benefits for both energy efficiency and animal welfare.

This project provides valuable insights for practitioners seeking to adopt sustainable practices in livestock farming, highlighting the feasibility and advantages of incorporating RES technologies.

The RES4LIVE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement No 101000785.

RES4LIVE
ENERGY SMART LIVESTOCK FARMING TOWARDS ZERO FOSSIL FUEL CONSUMPTION

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AGRICULTURE & INNOVATION

Renewable energy systems for the defossilization of an experimental dairy cattle farm

For the defossilization of an experimental dairy cattle farm, renewable energy systems (RES) were combined to provide electrical power for various devices as well as to replace diesel-powered machines with ones that can use biomethane instead.
The RES on this farm include a biomethane upgrade plant, a former diesel tractor that was converted to run on compressed natural gas (CNG), a sensor-operated tube ventilation and cooling system for a dairy barn, and a set of photovoltaic thermal (PVT) panels with a heat storage tank.

The base for this was an existing biogas plant with a combined heat and power plant (CHP) that is already able to provide the farm with electrical power and sells excess electricity to the national grid. In addition, the CHP provides thermal energy for heating the farm's office buildings. The biogas plant is fed with the slurry of the dairy cattle on the farm, and the dairy cows are housed in naturally ventilated barns. Since heat stress has become an issue in dairy cows increasingly, the barn was equipped with a combined tube ventilation and cooling system that operates sensor-based and detects climate conditions that lead to heat stress. Based on environmental sensors that track temperature, relative humidity, and gas concentrations in the barn, the natural ventilation of the barn is supported by injecting ambient air from outside the barn through ventilation tubes with exhaust nozzles above the lying cubicles and the feed table as soon as a first temperature threshold is exceeded. When the temperature rises further, additional ambient air can be pre-cooled in evaporative cooling pads and mixed into the ventilation airflow to drop the air outlet temperatures and mitigate heat stress conditions in the barn. The heat stress situations naturally are more prominent in the warmer half of the year, which allows the use of a PVT system as a synergy. The solar panels provide extra electricity at the time when it is needed for the barn climate system. In addition, the PVT system provides thermal energy that can be used to partly replace the boiler that supplies hot water that is regularly used e.g. for cleaning milking equipment.

The farm tractor that is regularly used to feed the dairy cattle had its diesel engine converted to now use CNG. The conversion process kept the tractor's power level and improved the emission level. The CNG is provided by the biomethane upgrade plant that uses a single membrane and a dual-purpose compressor to concentrate the biogas to a methane content of at least 95 % and store the then-compressed gas at a pressure of 250 bar. The prototype scale plant already produces more than enough CNG to run a tractor.

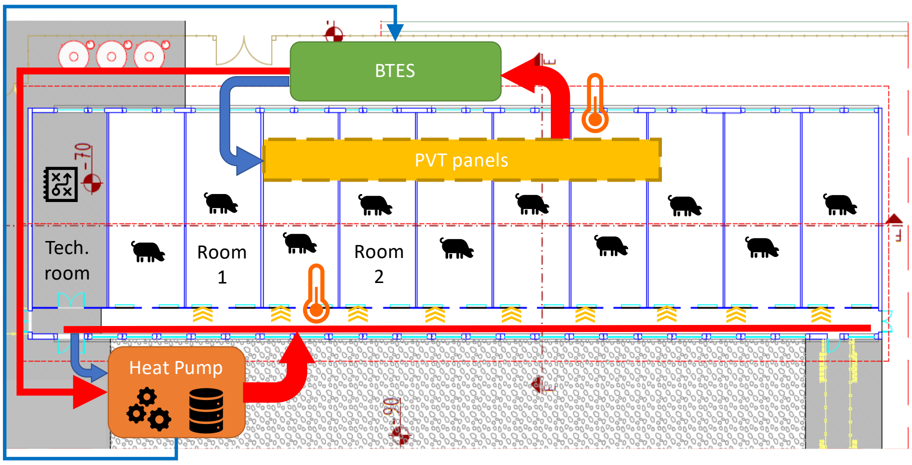
Integrated RES systems at the LVAT dairy cow farm

- A PVT system with a solar station providing an average electrical energy of 4.50 MWh per year and an average thermal energy of 24.75 MWh
- Thermal energy short term storage tank with 1,500 L capacity
- Prototype off-grid BioCNG upgrade plant with a capacity to produce up to 10 $Nm^3\ h^{-1}$ CNG with at least 95 % methane content at a storage pressure of 250 bar, with on-farm filling station
- A diesel farm tractor converted to use CNG from renewable sources
- Sensor-controlled tube ventilation and cooling system for a dairy barn

The RES4LIVE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement No 101000785.

An integrated renewable energy system for the decarbonization of swine farms

A sustainable heating system was developed for pig barns as an alternative to fossil-fuel-based ones. It consists specifically in an integrated Renewable Energy Source (RES) system incorporating a borehole thermal energy storage (BTES) and photovoltaic thermal (PVT) collectors, integrated with a Dual-Source Heat Pump (DSHP). A sophisticated control system was developed and implemented to monitor energy usage and environmental conditions. The results of pilot installation and experimental trials showed that a tailored mix of RES can be effectively established for a given livestock farm, leveraging the renewable resources prevalent in farming environments.



The heating load provided by the geothermal heat pump can rise the temperature of the radiant pipes up to 55°C, i.e. the operating temperature targeted with the previous fossil-based plant. The fundamental system architecture incorporates a dual-source heat pump featuring not only an air-cooled evaporator but also a heat exchanger for transferring heat with a water/glycol blend sourced from a sequence of PVT collectors connected to boreholes. The primary novelty of the system resides in its capability for hybrid operation, enabling simultaneous utilization of both ground-sourced and air-sourced heat, resulting in increased heating capacity and COP efficiency.

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Practice Abstract n. 20

RES4LIVE
ENERGY SMART LIVESTOCK FARMING TOWARDS ZERO FOSSIL FUEL CONSUMPTION

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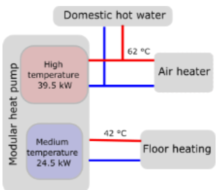
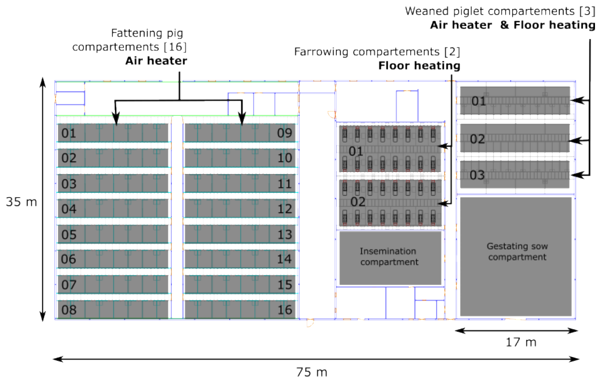
An integrated renewable energy source (RES) system for the decarbonization of experimental swine farm

An integrated renewable energy system (RES) was designed and implemented for an experimental swine farm as a sustainable alternative to the fossil-fuel-based heating system. The RES setup includes 24 photovoltaic thermal (PVT) collectors, two modular heat pumps, and a thermal energy storage tank. The control system monitors the heat energy supply, while a network of sensors tracks environmental conditions. Monitoring and evaluation results highlight the system's efficiency and effectiveness in replacing the farm's fossil fuel-based gas boilers, demonstrating the viability of this renewable solution for meeting the farm's heating needs.

The farm's heating requirements include air heating for the fattening pig compartments, floor heating for the farrowing compartments, and a combination of air and floor heating for the weaned piglet compartments. The entire heating demand is met year-round by the integrated renewable energy system (RES). Previously, a fossil-fuel gas boiler was used to heat circulating water to 70 °C for these needs. Now, two modular heat pumps have been installed: a high-temperature pump that heats the water to 62 °C and a low-temperature pump that heats it to 42°C. Additionally, the RES system offers a hybrid operation feature, allowing it to simultaneously utilize heat from both PVT panels and air sources, which enhances heating capacity and improves the system's coefficient of performance.





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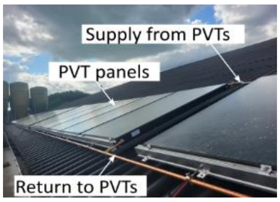
Practice Abstract n. 20

RES4LIVE
ENERGY SMART LIVESTOCK FARMING TOWARDS ZERO FOSSIL FUEL CONSUMPTION

eip-agri AGRICULTURE & INNOVATION

Integrated RES system at ILVO swine farm

- A PVT system with a solar station unit to generate 8.4 kW_{el} electrical energy, and 32.8 kW_{th} thermal energy.
- Thermal energy storage tank that stores the thermal energy from the PVT that is used to increase the heat pump coefficient of performance.
- Two modular heat pumps
  - 24.5 kW medium temperature
  - 39.5 kW high temperature
- Smart control and sensor system.



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Practice Abstract n. 21

RES4LIVE
ENERGY SMART LIVESTOCK FARMING TOWARDS ZERO FOSSIL FUEL CONSUMPTION

eip-agri AGRICULTURE & INNOVATION

Assessment of Integrated Renewable Energy Systems in an Experimental Egg-Laying Hens Farm

Integrating renewable energy systems (RES) could play a crucial role in enhancing the sustainability of livestock farming practices. A study conducted on a small experimental egg-laying hen farm in Greece assessed the animal welfare and productivity performance of such a system in comparison to the one before implementing RES, highlighting the potential benefits for poultry farmers from available funding to support its adoption.

The system implemented includes:

- A 9 kWp photovoltaic (PV) system to supply part of the farm's energy needs
- A 10 kW water-to-air heat pump for heating, cooling, and dehumidifying the indoor air
- An LED lighting system tailored to the hens' specific requirements
- A smart control system, incorporating both environmental sensors and energy meters

Prior to the RES4LIVE project, the farm's relatively simple and outdated system consumed low amounts of energy. While the new system is more energy-intensive, it significantly improves the thermal comfort of the hens by regulating indoor air quality, temperature, and humidity compared to the previous setup. This leads to enhanced animal welfare, increased productivity, and lower mortality rates.

SYSTEM	PERFORMANCE PARAMETERS	
Heat pump	SCOPCooling	SCOPHeating
	3.12	3.77
Photovoltaics	Conversion efficiency	
	10.4%	
	Self-Sufficiency (%)	Self-Consumption (%)
	22.81	84.12
Animal welfare and productivity	Decrease in mortality rate	
	28%	
	Increase in total egg production	Increase in average production per animal
	10%	19%

Although there is still much work to be done, adopting similar systems on poultry farms across Greece could improve animal welfare and productivity, with good potential of also improving their environmental and economic sustainability.

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AGRICULTURE & INNOVATION

Environmental and Economic Assessment of Renewable Energy Systems in an Experimental Dairy Cattle Farm

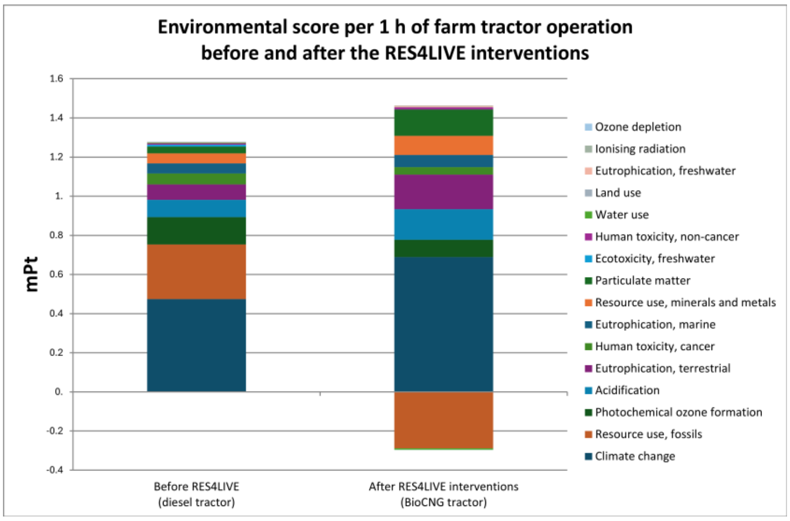
Integrating renewable energy sources (RES) systems into farming practices can greatly enhance operational efficiency and sustainability. This assessment examines the environmental and economic impacts of two innovative systems implemented on an experimental dairy cattle farm in Germany. The results suggest that cattle farmers can leverage these benefits and take advantage of available funding opportunities to support implementation.

The two systems evaluated are:

- A biogas-to-biomethane upgrading plant, equipped with a BioCNG filling station
- An adapted farm tractor for BioCNG use

The operation of the biogas-to-biomethane upgrading plant leads to remarkable diesel savings, causing a beneficial environmental effect equivalent to 4.6 times the total environmental burden of the biomethane supply chain system, only from the on-farm biomethane use in the retrofitted tractor. If all diesel savings are considered, including a potential sale of surplus BioCNG, the corresponding beneficial environmental effect could be increased up to 13 times.

The adapted tractor running on BioCNG offers additional environmental benefits compared to a conventional diesel tractor, reducing overall environmental burden by 9%, and the overall environmental burden caused by non-renewable fossil fuels and water consumption by 2 and 3 times, respectively.



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From an economic standpoint, considering both the sale of BioCNG and fuel savings, the discounted payback period (DPBP) for the biogas-to-biomethane upgrading plant is 10 years. With subsidies covering 20% to 40% of the total investment costs, aimed at promoting decarbonization at the EU level, the DPBP could be shortened to around 8 to 5 years, respectively. After that, the DPBP for the adapted tractor would be around 2 years.

Incorporating similar interventions could improve the environmental and economic sustainability of cattle farms producing biogas in Germany.

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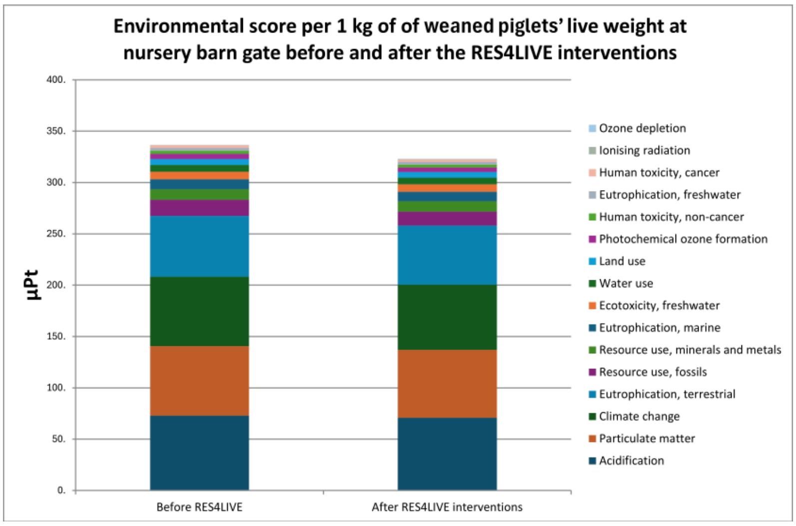
Environmental and Economic Assessment of Integrated Renewable Energy Systems in a Commercial Swine Farm

Adopting renewable energy systems (RES) can play a key role in improving the sustainability of farming practices. A study on a commercial swine farm in Italy evaluated the environmental and economic impacts of such a system in comparison to the system before installing RES, highlighting how swine farmers could benefit from available funding to support its implementation.

The system used includes:

- A 7.68 kWel - 25 kWth photovoltaic-thermal (PVT) system
- A multisource heat pump (35 kW)
- A 30m borehole thermal energy storage system
- A smart control system

When compared to the LPG boiler used before the project for heating the nursery barn of this farm, the RES4LIVE system could reduce the overall environmental burdens by 4%. This includes reducing the overall environmental burden caused by photochemical ozone formation (15%), non-renewable fossil resource consumption (15%), cancer-related human toxicity (13%), and climate change impact category (6%).



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Economically, with EU subsidies covering either 20% or 40% of the total investment costs to support decarbonization, the discounted payback period for this system could range from 21-22 years in the former case, to 13-14 years in the latter.

Implementing similar systems on swine farms in Italy could improve both environmental and financial sustainability.

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Practice Abstract n. 24

RES4LIVE
ENERGY SMART LIVESTOCK FARMING TOWARDS ZERO FOSSIL FUEL CONSUMPTION

eip-agri AGRICULTURE & INNOVATION

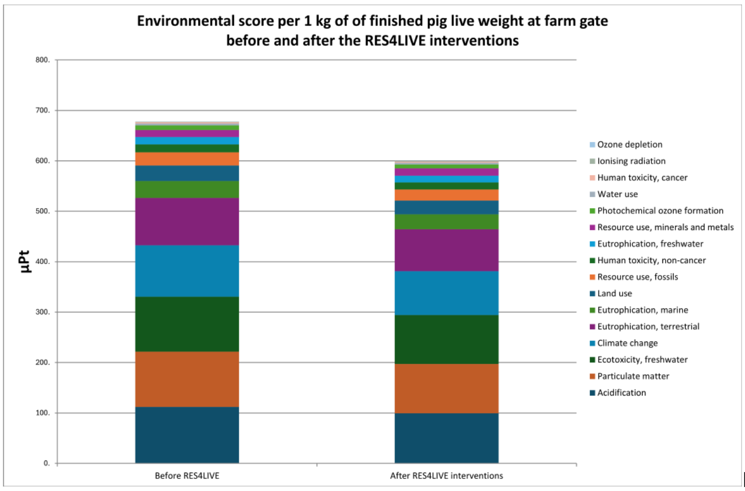
Environmental and Economic Assessment of Integrated Renewable Energy Systems in an Experimental Swine Farm

In the pursuit of sustainable farming practices, integrating renewable energy systems can significantly improve operational efficiency. The environmental and economic impacts of an integrated system on an experimental swine farm in Belgium are assessed, suggesting that swine farmers could capitalize on potential benefits and utilize available funding opportunities to support implementation.

The system includes:

- 24 photovoltaic-thermal (PVT) collectors
- Two multisource heat pumps, high-temperature (40 kW) and low-temperature (25 kW), equipped with a short-term heat storage tank
- A smart control system

Compared to the existing system—a natural gas boiler for space heating and domestic hot water—the integration of the RES4LIVE system has the potential to reduce overall environmental burdens by 12%. Specifically, it can reduce ozone depletion by 19%, non-renewable fossil resource consumption by 17%, and climate change impacts by 15%.



At the economic level, and considering subsidies ranging from 20% to 40% of the total investment cost, as a means to promote decarbonization at the EU level, the integrated renewable energy system can achieve a discounted payback period of approximately 13-14 years and 9-10 years, respectively.

Therefore, by incorporating similar interventions, swine farms in Belgium could enhance both their environmental and economic sustainability.

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Practice Abstract n. 25

RES4LIVE
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TOWARDS ZERO FOSSIL FUEL CONSUMPTION

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AGRICULTURE & INNOVATION

Social Assessment of Renewable Energy Sources (RES) Technologies Interventions in Livestock Facilities

The goal of the Social Assessment (SA) was to evaluate the social impacts of deploying Renewable Energy Systems (RES) technologies in livestock operations across the four pilot farms involved in the RES4LIVE project. The SA is critical for assessing potential energy upgrades in livestock farms, as it offers a comprehensive understanding of the project's social effects on various stakeholders. This ensures that the benefits go beyond cost savings and environmental protection to include improved social outcomes, increased community acceptance, and greater sustainability.

The social assessment indicated that the overall SA Index remained positive across all scenarios and analyses.

Results from all farms showed that most participants had a generally quite positive perception of the farm's transparency in operations and reporting, particularly with regard to energy efficiency and emissions reduction. The most notable positive social impacts were observed in areas such as Environmental and Ethical considerations, Health and Safety, Human Rights, and Governance.

However, many workers reported no significant improvements in wages or compensation during the project interventions, despite an increase in workload and/or working hours due to the RES initiatives. Areas for improvement include providing more comprehensive training for farm personnel on the operation of new RES technologies to ensure the smooth running of farm operations. Additionally, efforts should be made to reduce disruptions during and after the installation of the systems.

This social impact analysis highlighted the positive effects of the RES4LIVE technologies and provided valuable insights, showing that future implementations of RES technologies can be better aligned with stakeholder expectations and lead to even more positive social outcomes.

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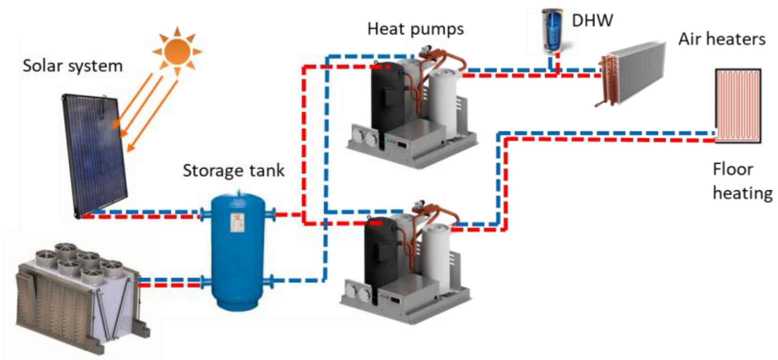
Innovative heat pumps for swine farm applications

Transitioning to Renewable Energy Sources (RES) is vital for reducing the EU's livestock sector's environmental impact. Our initiative aims to decarbonize heating in European swine farms by integrating innovative dual-source heat pumps (DSHPs). These DSHPs are designed to replace traditional boilers for space heating and domestic hot water.

At a farrow-to-finish pig farm, two DSHPs replaced a 60 kW gas condensing boiler. The low-temperature (25 kW) provides floor heating at 42°C, while the high-temperature (40 kW) handles air heating and domestic hot water at 60°C. Combined with a photovoltaic thermal (PVT) system and a short-term thermal energy storage tank, the HPs achieve a higher Coefficient of Performance (COP). A dry cooler supplements the system when solar energy is inadequate. The system operated 85% in air-water mode and 15% in water-water mode, with average COPs were 2.95 for the high-temperature HP and 4.87 for the low-temperature HP in air-water mode, and 9.85 and 4.10, respectively, in water-water mode.



In a second pilot farm, a multi-source HP replaced a 34 kW LPG boiler for the nursery barn's heating system. Here, PVT collectors are linked to a borehole thermal energy storage system, facilitating long-term heat storage. The HP utilized ambient heat via dry cooler. The HP maintained hallway temperatures near the setpoint, operating 17.4% of the time. It delivered 75% of its heat in ground mode and 25% in hybrid mode, with no air mode activation. The average COPs were 4.67 (ground), 3.50 (hybrid), and 4.34 (overall). This project offers valuable insights for practitioners seeking to adopt sustainable practices in

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AGRICULTURE & INNOVATION

Innovative Photovoltaic-Thermal (PVT) systems for dairy cattle farms

Figure 1: Solar house with solar pumping station, 1500L heat storage tank, and electrical

Intensive livestock farming consumes a considerable amount of thermal and electrical energy, especially in dairy farms where hot water is needed for cleaning the milk tanks, barn, and disinfection of the milking machines. Therefore, Photovoltaic thermal (PVT) collectors, that convert solar radiation into usable thermal and electrical energy are a promising form of renewable energy generation for agriculture and livestock farming specifically. A heat storage tank can be used to store excess heat during the day for use at night.

In dairy farms with milk storage, heat can be recovered from the milk chillers to pre-heat any water for domestic hot water use. It was decided to use high performing PVT collectors to further heat up the pre-heated water to the desired 60°C for hot water use in the farm.

LVAT Dairy Farm PVT Installation Highlights

- 24 Solarus concentrating PVT collectors (55 m^2) were installed to take heat from the heat recovery system and further heat the water to the desired domestic hot water temperature for the farm.
- Expected annual solar heat supply to the farm of 7.5 MWh with 24 Solarus PVT collectors.
- Expected annual electric PV supply to the farm of 4 MWh with 24 Solarus PVT collectors.
- Annual maintenance costs are less than 500 EUR.
- With the heat recovery system and PVT installation, the e-boiler for domestic hot water is only expected to run during the winter for top up of heat.
- Expected return on investment is less than 8 years, which can be reduced with increasing gas and electricity prices as well as increasing price volatility.

Figure 2: Concentrating PVT installation at LVAT dairy farm in Potsdam, Germany

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Innovative Photovoltaic-Thermal (PVT) Systems for Swine Farms

Intensive livestock farming consumes a considerable amount of thermal and electrical energy, especially in swine farms where piglets need heating all year round. Therefore, Photovoltaic thermal (PVT) collectors, that convert solar radiation into usable thermal (for hot water and space heating) and electrical energy are a promising form of renewable energy generation for agriculture and livestock farming specifically. A heat storage tank can be used to store excess heat during the day for use at night.

To have available heat all year round, the PVTs can supply heat to a heat pump and thereby increasing the efficiency of the heat pump by up to two times. This was the case in the ILVO pilot farm in Belgium. PVT collectors can also be combined with a geothermal seasonal heat storage system to store excess heat during the summer for the winter. This is case in the Golinelli swine farm in Emilia-Romagna, Italy.

ILVO Swine Farm PVT System with Heat Pump Highlights

- 24 Abora aH72 PVT collectors (45m^2) were installed in combination with 2 heat pumps that deliver the final space and domestic hot water heat to the farm.
- Expected annual solar heat supply to the farm of 15 MWh to 21 MWh with 24 Abora aH72 PVT collectors.
- Expected annual electric PV supply to the farm of 4 MWh with 24 Abora aH72 PVT collectors.
- Annual maintenance costs are less than 500 EUR.
- With the heat pump and PVT installation, no gas is expected to be consumed by the farm all year round.
- Expected return on investment is less than 8 years, which can be reduced with increasing gas and electricity prices as well as increasing price volatility.

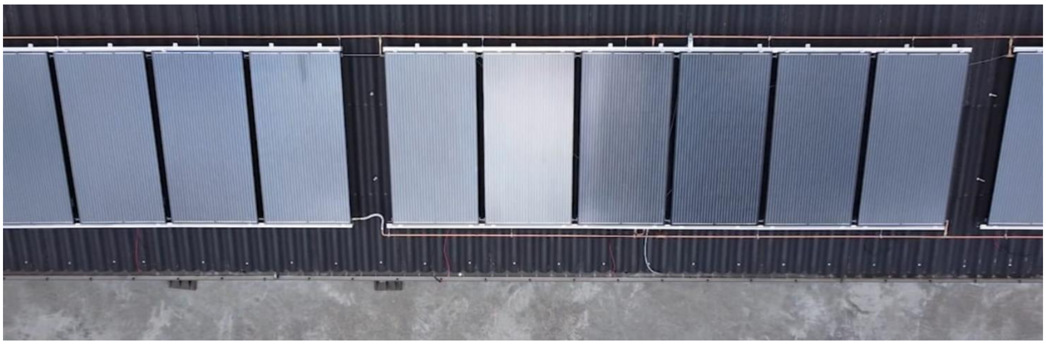

Figure 1: PVT collectors at ILVO swine farm in Belgium, before insulation of pipes

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Installation Practices for Indoor/ Outdoor Smart Control Systems in Livestock Buildings

Smart control systems for livestock buildings offer a transformative solution for farmers seeking to improve the efficiency, welfare, and sustainability of their operations. Our work focuses on best practices for the installation of both indoor and outdoor systems that monitor and control vital elements such as temperature, humidity, lighting, and air quality in livestock environments.

By implementing these systems, farmers can reduce energy costs, enhance livestock welfare, and increase overall productivity. Automated controls allow for precise adjustments in real-time, ensuring optimal living conditions for livestock without requiring constant manual oversight. For example, the smart control system can automatically adjust ventilation based on humidity levels, reducing the risk of disease.

From a cost-benefit perspective, the initial investment in smart control systems is offset by long-term savings in energy consumption, reduced labor, and fewer losses due to health-related issues. Additionally, data generated from these systems helps farmers make informed decisions about resource allocation, animal health, and operational efficiency.

Farmers adopting these smart technologies are better equipped to meet industry demands, reduce costs, and improve the welfare of their livestock, leading to a more sustainable and profitable future.

Figure 1: Chart with environmental data

Smart control installation highlights in RES4LIVE

- 4 pilot farms (Belgium, Germany, Greece, Italy)
- 2 Swine farms, 1 Poultry farm, 1 Dairy farm
- Environmental sensors (Weather stations, Temperature, Humidity, CO_2, NH_3, H_2S, O_2, VOC)
- Energy consumption sensors
- Integration with various systems (Heat Pump, PVT, Ventilation, Anemometers, Biogas)
- Automation (Heat Pumps, Ventilation)
- Alerts though a notification system

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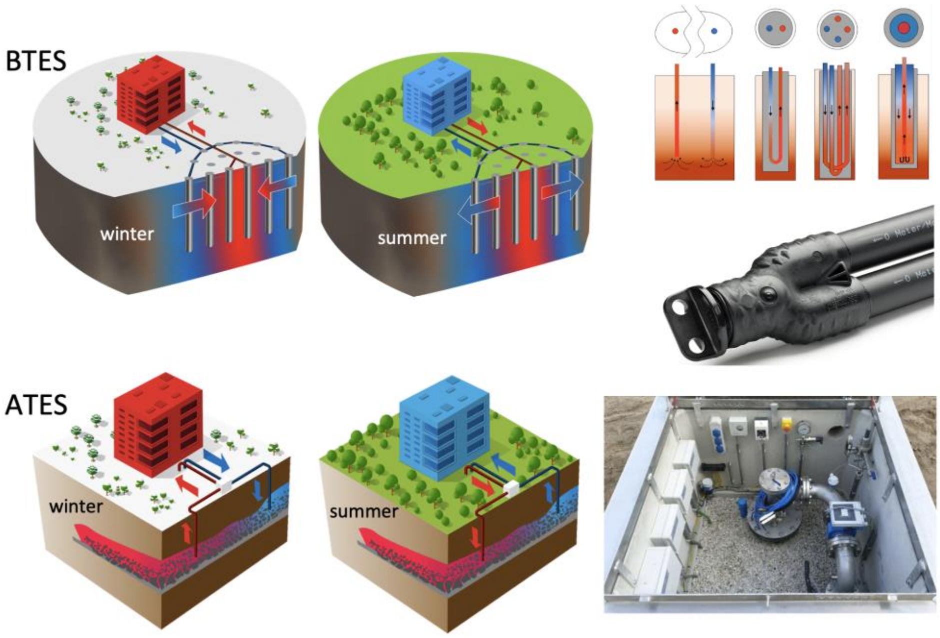
AGRICULTURE & INNOVATION

Geothermal potential for livestock farming applications in Europe

The use of renewable energy sources can ensure that the cost of barn climatization can remain low. Geothermal energy can certainly be an alternative here. Moreover, shallow geothermal energy can play an important role in maintaining summer comfort. Borehole thermal energy storage (BTES) uses vertical loops to exchange thermal energy. Aquifer thermal energy storage (ATES) systems use wells with extraction and injection of groundwater. It is prohibitively expensive to deploy classical compression cooling for this purpose. Geothermal energy offers opportunities to use passive cooling to also prevent overheating with minimal energy costs. As an alternative, smart active cooling with geothermal reversable heat pumps offers a solution to increase animal comfort and productivity up to an optimal level.



Geothermal energy concept for Pig Farm in Belgium

The research site of ILVO in Belgium (the Pig Farm) suits best for the integration of a central geothermal system with BTES. The barn is relatively young (recently built) and equipped with modern HVAC installations, consisting of radiant panels (twin tubes), floor heating combined with an extensive ventilation system. This installation can be relatively well adapted to integrate barn cooling.

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