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Anaerobic co-digestion of chicken litter and raw glycerol

as a sustainable tool for the waste management of a Slovak poultry farm and to reduce its energy consumption

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INTRODUCTION

- Worldwide: **21 billion** stocks of chicken
- **Industrial poultry farms** produces:
  - 74 % of raised chicken
  - 68 % egg production

FAO

Worldwatch Institute

INTRODUCTION

- **Poultry manure**
  - **Solid waste,** traditionally used to enrich soils and as fertilizer
  - Carbon-rich waste, with significant content of N, P, S, K
- **Environmental concerns**
  - **Agricultural run-off**: Low N/P ratios leads to excessive application of P in the soil if application rates of manure are based on N requirement
  - **GHG emissions** from large manure pits: $\mathbf{CH_4}$, $\mathbf{N_2O}$, $\mathbf{CO_2}$, $\mathbf{SO_2}$
  - **Traditional manure management** contributes to: Acidification of soils, eutrophication of waters, air pollution and global warming

Hong et al (2014)

INTRODUCTION

- **Anaerobic digestion**
  - **Sustainable tool to manage manure,** based on a natural decomposition process that happens in the absence of oxygen
  - **High biodegradability** of poultry manure
  - **Organic matter** contained in manure is transformed to **biogas**
  - Produces a **digestate** with improved characteristics
  - **Low C/N ratio** leads to ammonia accumulation: Toxicity and inhibition of the AD process (mostly methanogenesis)

Angelidaki et al., 1994
Borowski et al., 2013

Anaerobic co-digestion

- **Feasible technique to mitigate ammonia accumulation and inhibition**
- **Crude glycerol** is a C-rich waste material that can be used as co-substrate
- **Optimize C/N ratios** and improves process kinetics
- **Co-digestion ratio** must be carefully managed to prevent overloading of reactors and to achieve the necessary degree of mineralization for stabilized sludge

Abouelenien et al., 2010

Jensen et al., 2014

Astals et al., 2012

CASE STUDY – The poultry farm

Major-size poultry farm located in Western Slovakia

- **158,000 chickens** in a growth cycle

Growth cycle: **42 days feeding of chicken + 18 days time gap**
Weigh of chicken at the end of a cycle: **2700 g**

- **360 Mg of chicken litter** in a growth cycle

184 Mg TS (Dry matter)
158 Mg VS (Organic matter)

0.054 kg hd^{-1} d^{-1}
512 g TS kg^{-1}
438 g VS kg^{-1}

- **6 Mg (2.6 Mg VS)** ← **DAILY**

CASE STUDY – The poultry farm

Consumption of natural gas

- **Heating** of **broiler sheds (13)**
- Operational temperature **33 °C**
- Operational days in a calendar year: **252 d**

		$Nm^3\ d^{-1}$	$GJ\ d^{-1}$
-	**In summer days (84 d)**	100	3.3
-	**In winter days (84 d)**	2,500	81.6
-	**Transitional weather (84 d)**	1,200	39.2

Consumption of electrical energy

- Mainly lights, feeding system, exhaust and ventilation fans, pumps

2,000 $kWh\ d^{-1}$

ENERGY

CONSUMPTION

320,000 $Nm^3\ y^{-1}$

10,500 $GJ\ y^{-1}$

630 $MWh\ y^{-1}$

Aim of this work

KEY QUESTIONS

1. Does anaerobic co-digestion help to prevent/mitigate ammonia inhibition?

2. Can the anaerobic process be stable in the long-term?

3. Can we take advantage of the chicken manure and cover the energy needs of the poultry farm?

MATERIALS AND METHODS

Chicken litter

- Fresh samples of chicken litter were collected directly from the poultry farm and stored in a laboratory freezer at **-18 °C**
- Besides excrements and urine, litter contains also straw (**5-10 %w/w**)
- Chicken litter was grinded and analysed; then, placed in individual bags and stored **at 4 °C** for immediate use

C/N	**15**	± 3	
TS	**512**	± 135	**g TS kg^{-1}**
VS	**438**	± 131	**g VS kg^{-1}**

MATERIALS AND METHODS

Raw glycerol

- Samples of residual raw (crude) glycerol were collected from a bio-diesel plant located 80 km away from the poultry farm

Inoculum

- Anaerobic sludge from another laboratory reactor with a previous experiment using poultry litter as main substrate

C/N	**> 20**	
VS	**814** ± 4	**g TS kg^{-1}**
COD	**1,372** ± 28	**g L^{-1}**

COD	**8.5** ± 0.5	**g L^{-1}**
TAN	**1.7** ± 0.12	**g L^{-1}**
TS	**37** ± 5	**g L^{-1}**

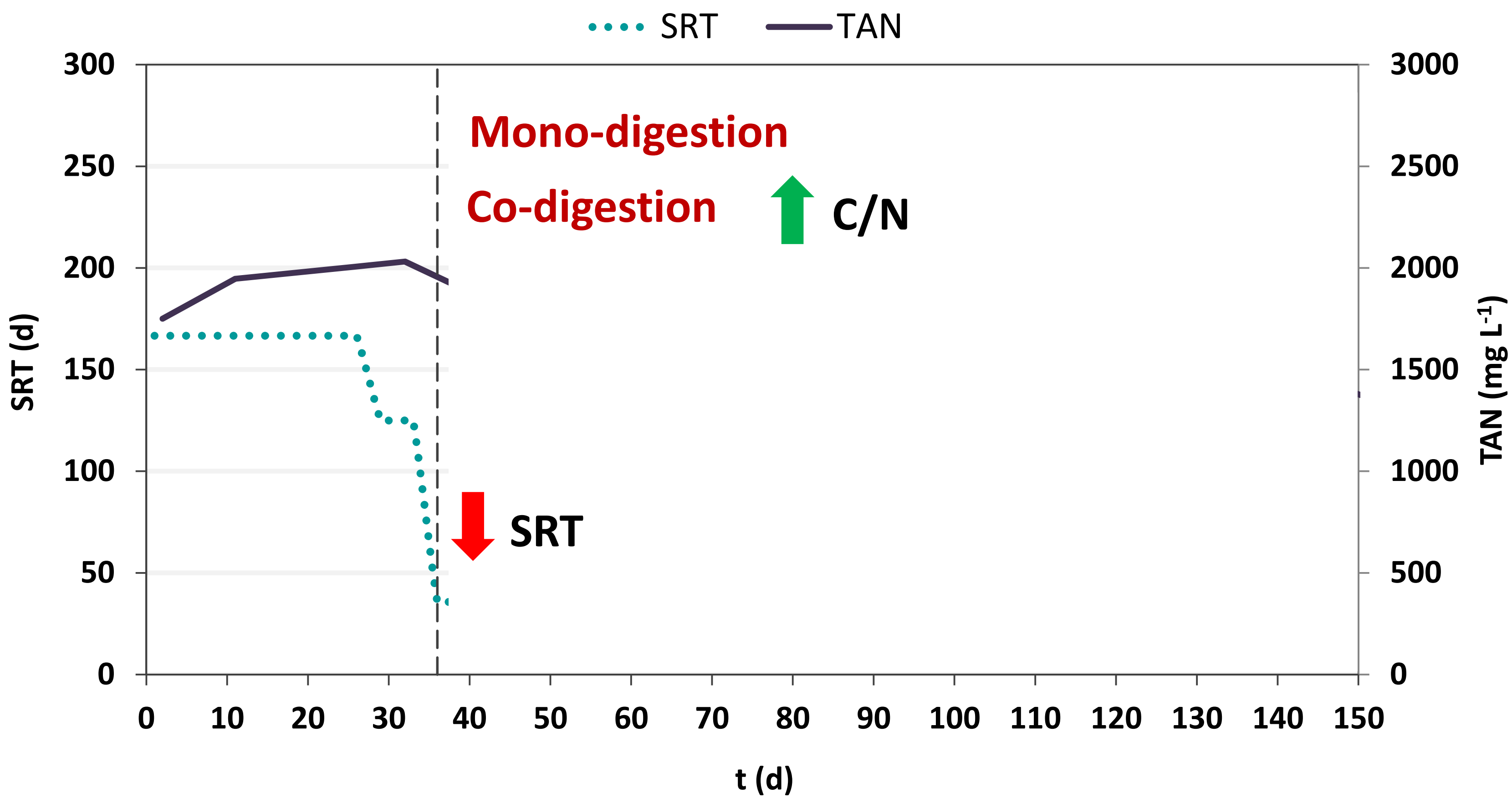
EXPERIMENTAL SET-UP

SRT

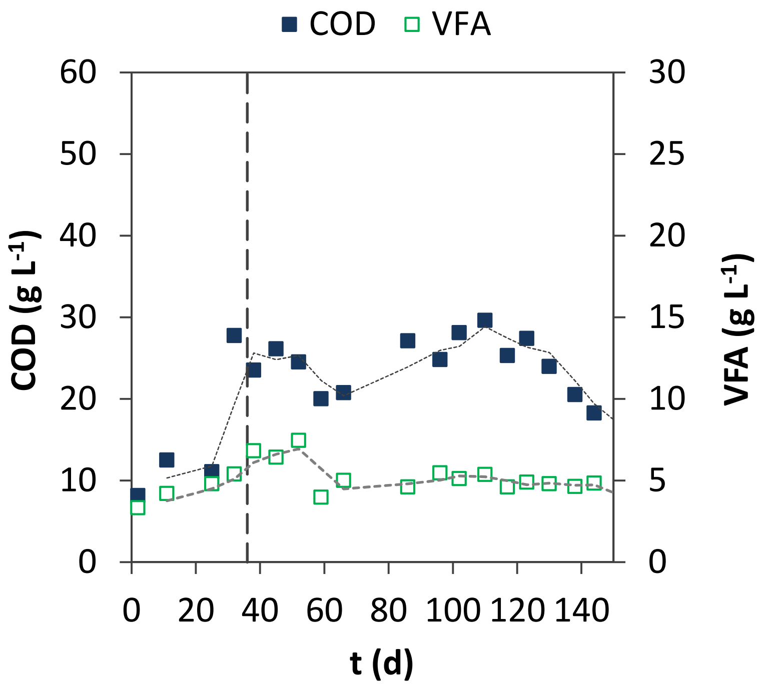
C/N

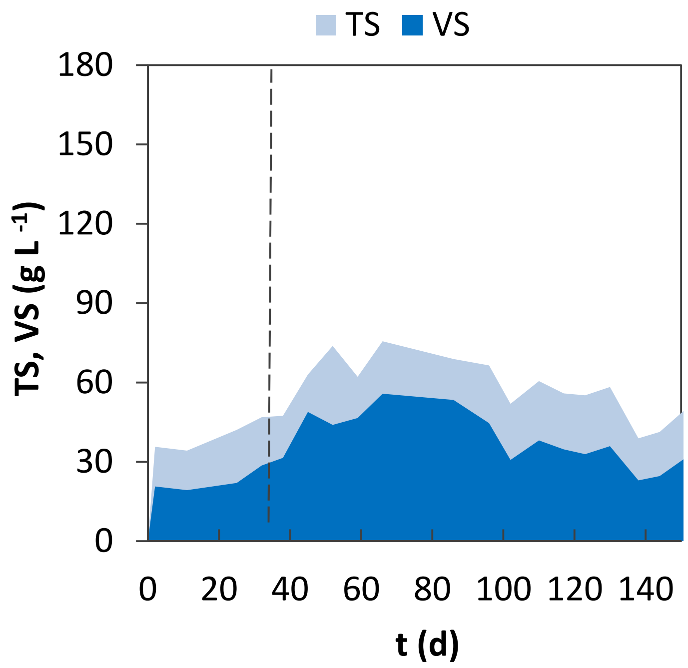
Q_B

EXPERIMENTAL RESULTS

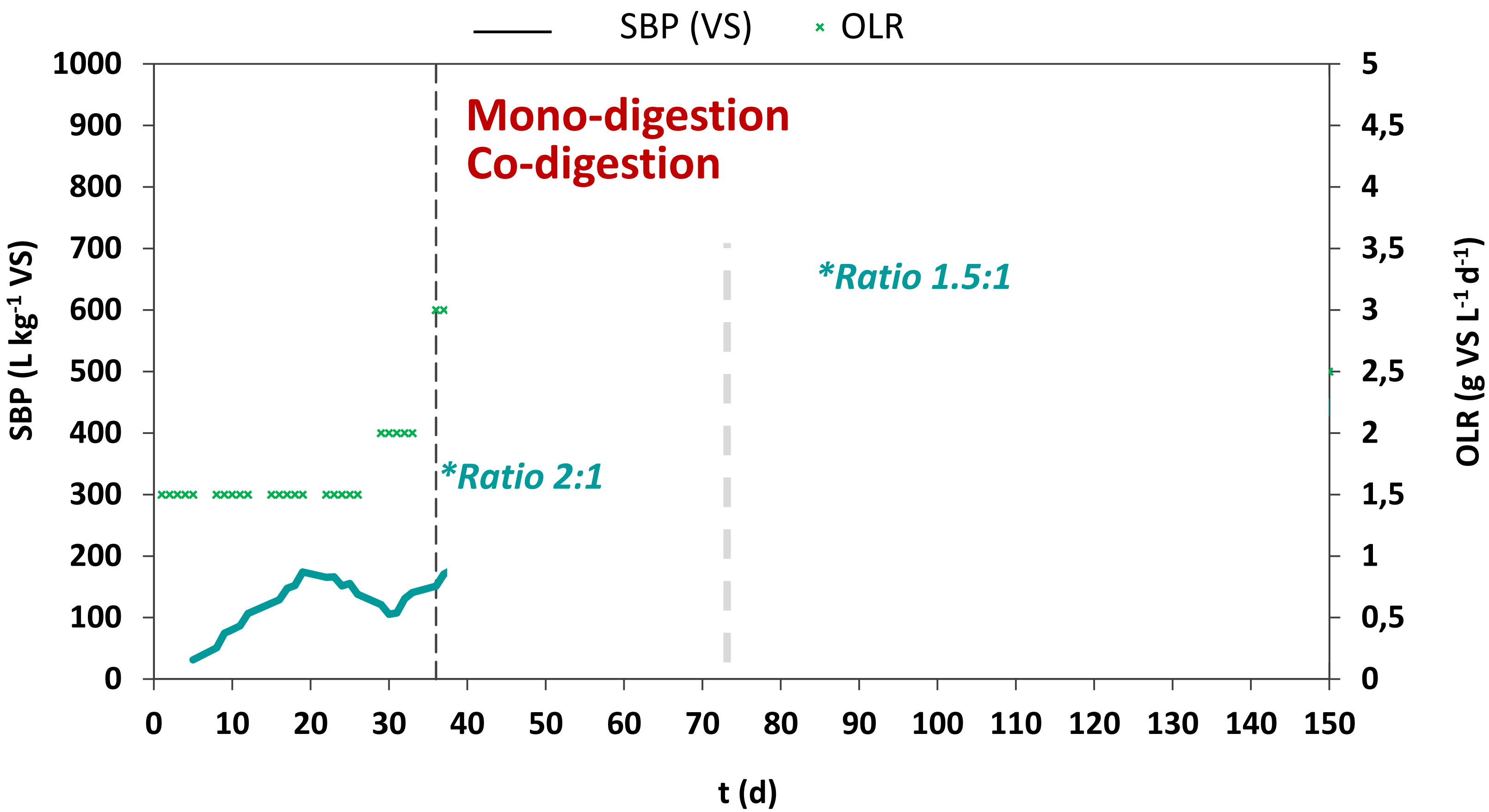


EXPERIMENTAL RESULTS





EXPERIMENTAL RESULTS



DISCUSSION: Technological design of the biogas plant

- Based on experimental results

Chicken litter 6 Mg d^{-1}

OPERATION

OLR = 2.5 g VS L^{-1}

SRT = 51 d

AcoD ratio = 1.5 : 1

Θ = 37 °C

pH = 7.23

SLUDGE

COD_s = 18.5 g L^{-1}

VFA = 4.6 g L^{-1}

TAN = 1.4 g L^{-1}

TS = 5.8 %

VS = 3.8 %

BIOGAS

SBP_V = 1.15 L L^{-1}

SBP_{VS} = 460 L kg^{-1} VS

CH_4 = 54 %

CO_2 = 43 %

H_2S = 2520 ppm

Scale-up

Volume of sludge	1,750	m^3
Volume of digester	2,200	m^3

Technological parameters

DISCUSSION: Technological design of the biogas plant

OPERATIONAL PARAMETERS

OLR = 2.5 g VS L^{-1}

SRT = 51 d

AcoD ratio = 1.5 : 1

Feedstock parameters

Feeding rate	$M_{total,in}$	**34.2**	**Mg d^{-1}**
Dry matter feeding rate	$TS_{total,in}$	4.9	Mg TS d^{-1}
Organic feeding rate	$VS_{total,in}$	**4.4**	**Mg VS d^{-1}**
Co-digestion ratio	VS_{litter}/VS_{GLY}	**1.5**	**-**
Chicken litter feeding rate	M_{litter}	**6.0**	**Mg d^{-1}**
Daily chicken litter input (TS)	TS_{litter}	3.1	Mg TS d^{-1}
Daily chicken litter input (VS)	VS_{litter}	2.6	Mg VS d^{-1}
Raw glycerol feeding rate	M_{GLY}	**2.1**	**Mg d^{-1}**
Daily raw glycerol input (VS)	VS_{GLY}	1.7	Mg VS d^{-1}
Fresh water input	M_{water}	**26.1**	**Mg d^{-1}**

DISCUSSION: Technological design of the biogas plant

Biogas production rate

Biogas production rate	Q_{biogas}	**2,005**	**$Nm^3\ d^{-1}$**
Methane production rate	Q_{CH4}	1,085	$Nm^3\ d^{-1}$
Engine power (CHP)	P_{CHP}	190 - 250	kW
Electrical energy	E_{el}	**4,560**	**$kWh\ d^{-1}$**
Thermal energy (heat)	E_{th}	**24,624**	**$MJ\ d^{-1}$**
Income for electricity	I_{el}	502	$€\ d^{-1}$
Sulphur recovery potential	S_{out}	7.1	$kg\ S\ d^{-1}$

BIOGAS

SBP_V = 1.15 $L\ L^{-1}$

SBP_{VS} = 460 $L\ kg^{-1}$ VS

CH_4 = 54 %

CO_2 = 43 %

H_2S = 2520 ppm

DISCUSSION: Technological design of the biogas plant

Stabilized sludge

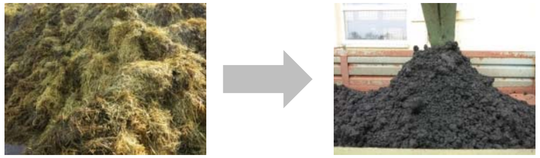
Digestate production rate	$M_{total,out}$	29.8	$Mg\ d^{-1}$
Digestate (TS) production rate	$TS_{total,out}$	1.7	$Mg\ TS\ d^{-1}$
Supernatant production rate	$M_{supernatant}$	22.9	$Mg\ d^{-1}$
Nitrogen recovery potential	N_{out}	25.0	$kg\ N\ d^{-1}$
Phosphorus recovery potential	P_{out}	1.5	$kg\ P\ d^{-1}$

SLUDGE

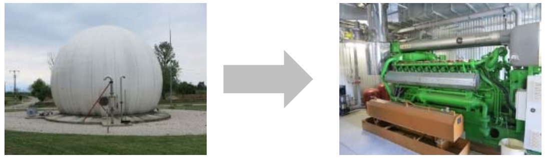
TS = 5.8 %
VS = 3.8 %
COD_s = 18.5 g L^{-1}
VFA = 4.6 g L^{-1}
TAN = 1.4 g L^{-1}
PO_4-P = 198 mg L^{-1}

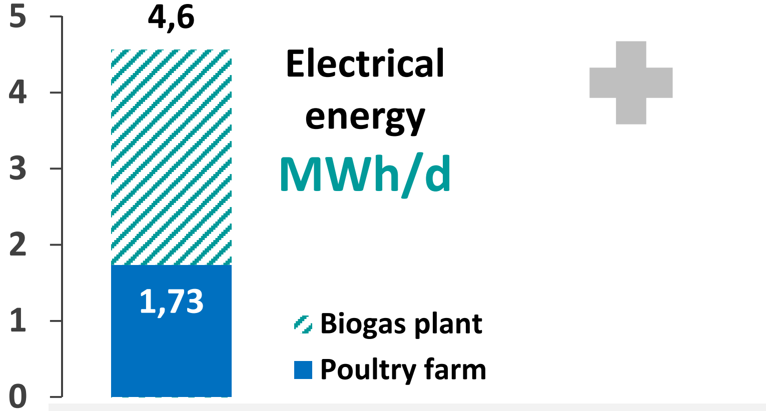
DISCUSSION: Balance overview

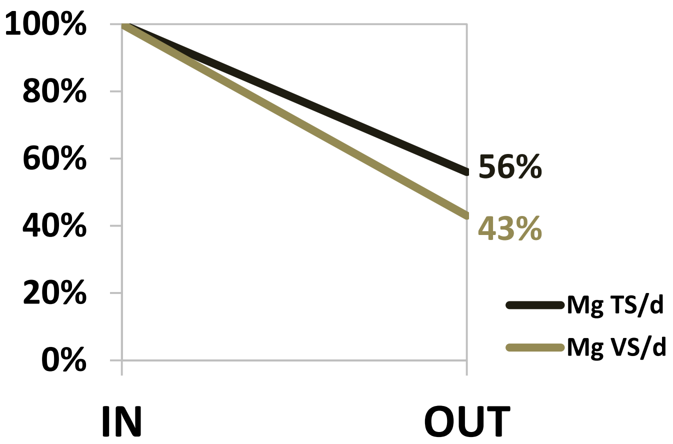
Waste management

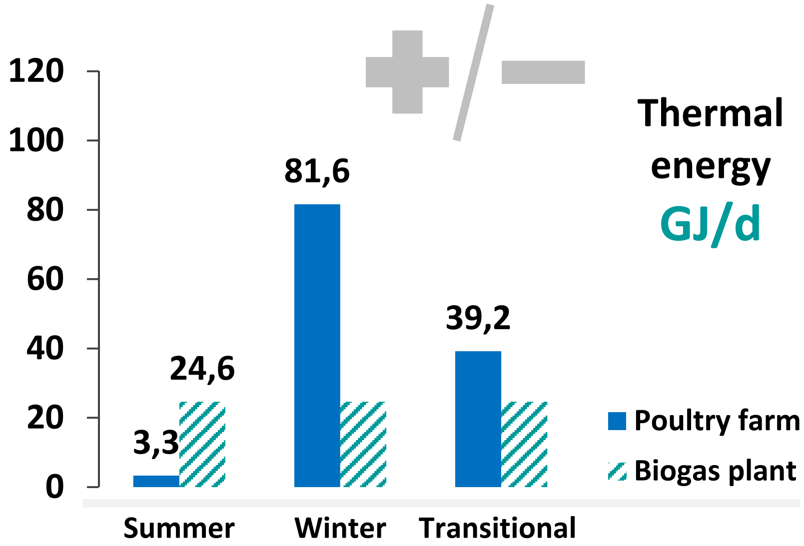


Energy









Application of research outcomes

Socio-economic challenges

- **<u>Convincing farm authorities</u>** and decision-makers to **<u>move from traditional techniques to anaerobic digestion</u>** is mostly a hard job
- **<u>Getting financing</u>** from banks and investors or access to funds, loans, etc.
- Long payback of the biogas plant (BP)

  The **fluctuation nature of the current global economy** can cause the poultry farm to close or decrease its production, jeopardizing the operation of the BP

- **Reaching a long-term compromise** with the inhabitants of surroundings towns

Technical drawbacks

- High **<u>water</u>** consumption of the plant (Enable recirculation of supernatant?)
- **<u>Digestate</u>** quality parameters have to be improved (**COD** concentration stills to high)
- High content of **<u>hydrogen sulphide</u>** in biogas (H_2S removal in scrubbers?)

Application of research outcomes

Strengths

- AD process **contributes to mitigate the emission of greenhouse gases from manure** into the atmosphere, enhancing **CH_4-sequestration**
- **Manure management** of the poultry farm is solved in a more **sustainable way**
- **Biogas production rates can partially cover the energy needs of the poultry farm** (both thermal and electrical energy), reducing operational costs of the farm and generating a surplus that can be further commercialized
- **Digestate** possess attractive fertilizing properties
  - High content of N, P and K (and S in both digestate and ammonia); nutrients are easily assimilable for crop production
  - Nutrients recovery is possible
- The implementation of a BP **may generate more local jobs**

CONCLUSIONS

1. **Chicken litter** produced in the poultry farm is a **valuable substrate for biogas production**. **AcoD of chicken litter and raw glycerol** showed in general, a **positive impact on the anaerobic process** and helped to mitigate and prevent inhibition of the anaerobic process by ammonia

2. A biogas plant of **V 2200 m^3** is proposed based on operational parameters **AcoD ratio 1.5** **OLR 2.5 g VS L^{-1} d^{-1}** and **SRT 51 d**. Thus, it would be possible to transform **2150 Mg** of **chicken litter** produced in 6 cycles (annual production) into **722 000 m^3 of biogas**, yielding about **1660 MWh of electricity** and **8900 GJ of heat**

3. Through anaerobic digestion, the **waste management** of the solid waste generated in a poultry farm **is improved** and the **energy needs** of the farm can be **partially covered**, bringing **substantial economic savings** to the farm.

4. AD can **help to mitigate environmental problems** related to animal manure, **making animal farming more sustainable.**

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