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Stelios Rozakis

Head - *Bioeconomy and Biosystems Economics Lab*

Faculty - ***Technical University of Crete***

Forestry and Habitats Online Knowledge Exchange Workshop

18/04/2024

Outline

- ***Background and motivations***
- *Methodology*
- *Case study*
- *Main results*
- *Conclusion and Policy Implications*

Institute of Soil Science
and Plant Cultivation
State Research Institute

BioEcon

Investigating bioeconomy development through economics lenses:
The case of the agricultural biogas industry in Lubelskie, Poland

Department
of Bioeconomy
and Systems Analysis

Stelios Rozakis, Andrea Bartoli, Kesheng Shu, Anna Jędrejek, Paria Sefeedpari

BACKGROUND AND MOTIVATIONS

- Biogas can supports bioeconomy development and may constitute a source of electrical and thermal energy supply
- Great potential of biomass in Poland (18,9 Mha of UAA) but about **130** agricultural biogas plants operating versus **7.000** in Germany
- Critical issues: **competition** between bioenergy and other agri-food supply chains? Additional **GHGs** emission due to LUC?

➢ We aim to develop a tool to comprehensively investigate:

i) consequences of biogas polices in Poland (feedstock used, biogas produced, LUC, effectiveness in reducing GHGs)

ii) Assess the most efficient incentive system for biogas production in Poland.

➢ By modeling the energy crops market for biogas: **supply**-side agricultural sector **Vs demand**-side biogas industry (**partial equilibrium micro-economic** framework).

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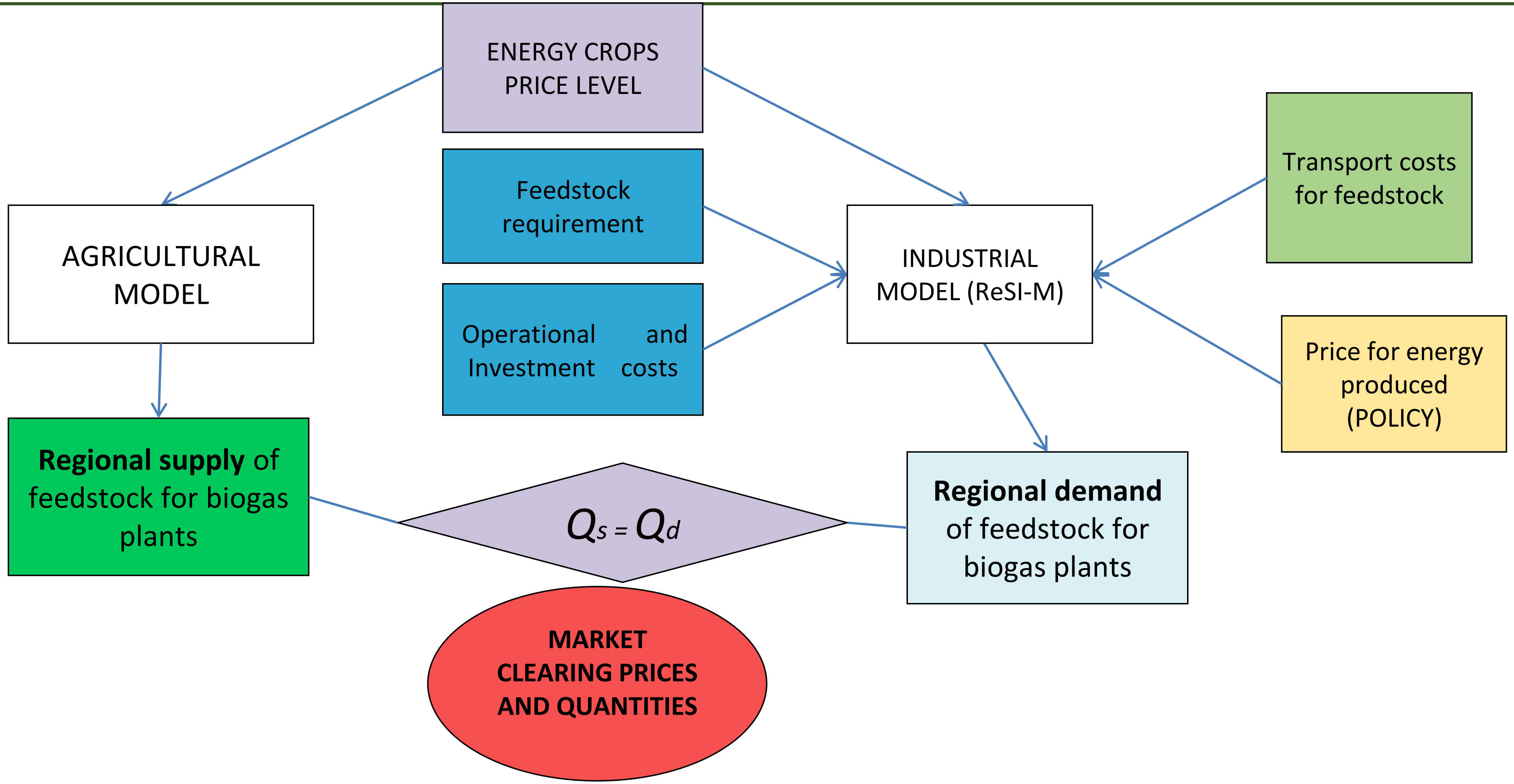
METHODOLOGY – THE INTEGRATED PE MODEL



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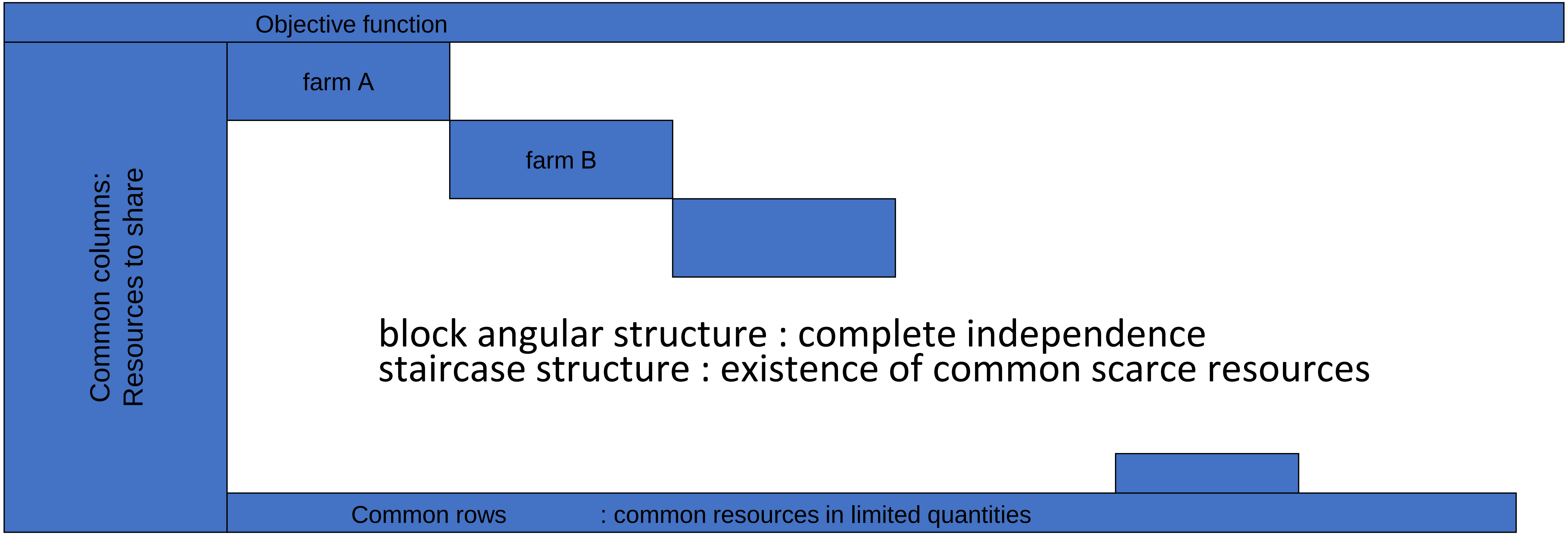
Sector model of arable agriculture:
simultaneous optimisation of independent decision making units (DMU)



Literature

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METHODOLOGY THE AGRICULTURAL SUPPLY MODEL

The optimized agricultural model is a regional recursive dynamic model (Shu et al., 2018)

Model equation	Mathematical structure	Description
Objective function	$WELFARE = REVENUE - COST$	***The sum of producer revenue in all commodity markets, minus specific and unspecific production cost and the cost of mudflat reclamation.***
Physical constraints	$LAND^{\text{concrop}} + LAND^{\text{enecrop}} \leq endowment^{\text{arableland}}$	The cultivated land in each region and time period cannot exceed given endowments.
	$\sum_{his}\left(landuse_{his}^{concrop} \times CMIX_{his}\right) = LAND^{\text{concrop}}$	Cropping activities are restricted to a linear combination of historically observed choices.
Technical constraints	$LAND_{a,t}^{\text{enecrop}} \leq LAND_{a-1,t-1}^{\text{enecrop}}$	The area of energy crop plantation in higher age classes cannot exceed the area of the corresponding previous age class in the previous period.
Policy constraints	$demand^{\text{biomass}} \leq utilization\ ratio \times yield^{\text{biomass}} \times LAND^{\text{concrop}} + yield^{\text{biomass}} \times LAND^{\text{enecrop}}$	Biomass production needs to satisfy minimum biomass demand.
	$demand^{\text{food}} \leq yield^{\text{food}} \times LAND^{\text{concrop}}$	Food production needs to satisfy minimum food demand.
Decision variables	$LAND^{\text{concrop}}, LAND^{\text{enecrop}}$	Cultivated area includes arable lands and mudflats; Crops in the model are divided into conventional crops and energy crops.
	$CMIX$	The weights of historical land use patterns for decisions on land use in future years.

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METHODOLOGY - THE INDUSTRIAL MODEL (RESIM)

- ReSI-M (Regionalized Location Information System – Maize; Delzeit et al., 2011) determines number, location and typology of plants in a sequential process.

- Maximizing the Return on Investment (ROI) for different biogas plants typologies:

  - kWh produced in one year y_s
  - Withdrawal price for energy (Gov. subsidization) p_s
  - Operational costs oc_s
  - Maize need $x_{c,s}$
  - Maize price w
  - Maize transportation cost $tc_{c,s}$
  - Investment cost I_c

$$ROI_{c,s} = \left[\frac{y_s p_s - oc_s - x_{c,s}\left(w + tc_{c,s}\right)}{I_c}\right]$$

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General Algebraic Modelling System

System Overview

GAMS is a high level modeling system for mathematical programming and optimization. It consists of a language compiler and a range of associated solvers.

The GAMS modeling language allows modelers to quickly translate real world optimization problems into computer code.

The GAMS language compiler then translates this code into a format the solvers can understand and solve. This architecture provides great flexibility, by allowing changing the solvers used without changing the model formulation.

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General Algebraic Modelling System

```
Sets
       i   canning plants    / Seattle, San-Diego /
       j   markets           / New-York, Chicago, Topeka / ;

Parameters
       a(i)  capacity of plant i in cases
         /    Seattle     350
              San-Diego   600  /
       b(j)  demand at market j in cases
         /    New-York    325
              Chicago     300
              Topeka      275  / ;

Table  d(i,j)  distance in thousands of miles
                  New-York       Chicago      Topeka
    Seattle          2.5           1.7          1.8
    San-Diego        2.5           1.8          1.4  ;

Scalar f  freight in dollars per case per thousand miles  /90/ ;

Parameter
       c(i,j)  transport cost in thousands of dollars per case ;
c(i,j) = f * d(i,j) / 1000 ;

Variables
     x(i,j)  shipment quantities in cases
     z       total transportation costs in thousands of dollars ;

Positive variables x ;

Equations
     cost         define objective function
     supply(i)    observe supply limit at plant i
     demand(j)    satisfy demand at market j ;
cost ..        z  =e=  sum((i,j), c(i,j)*x(i,j)) ;
supply(i) ..   sum(j, x(i,j))  =l=  a(i) ;
demand(j) ..   sum(i, x(i,j))  =g=  b(j) ;

Model transport /all/ ;

Solve transport using LP minimizing z ;
```

METHODOLOGY THE INDUSTRIAL MODEL INPUT (RESIM)

Industrial model contains detailed technical parameters for technology, cost and revenue data

									sorghum P	disc rate	life time	discount factor	
									40	3%	10	8.530203	
type of plant	***kW***	***invest***	***energy* generated kWh***	***withdrawal price***	***annual revenue***	***total annual costs***	***profit***	***return on investment***	***t/year sorghum needed***	***t/year manure needed***	*digestate output*		net profit
C1 - ICE	130	843994	1038960	0.25	259740	145639.8	114100.2	**13.5%**	**2730**	**8018**	4299.2	109200	4900.156
C2 - ICE	250	1386650	1998000	0.25	499500	242860.7	256639.3	**18.5%**	**5104**	**14990**	8037.6	204160	52479.32
C3 - ICE	530	2652846	4235760	0.25	1058940	468458.5	590481.5	**22.3%**	**10252**	**30107**	16143.6	410080	180401.5
C4 - ICE	1000	4778248	7992000	0.22	1758240	845757.4	912482.6	**19.1%**	**18608**	**73257**	36746	744320	168162.6
C5 - ICE	2000	9300379	15984000	0.22	3516480	1646524	1869956	**20.1%**	**35253**	**103531**	55513.6	1410120	459835.9
C6 - MGT	130	982101	1038960	0.25	259740	161830.2	97909.8	**10.0%**	**3675**	**10793**	5787.2	147000	-49090.2
C7 - MGT	250	1652240	1998000	0.25	499500	273995.9	225504.1	**13.6%**	**6563**	**19273**	10334.4	262520	-37015.9

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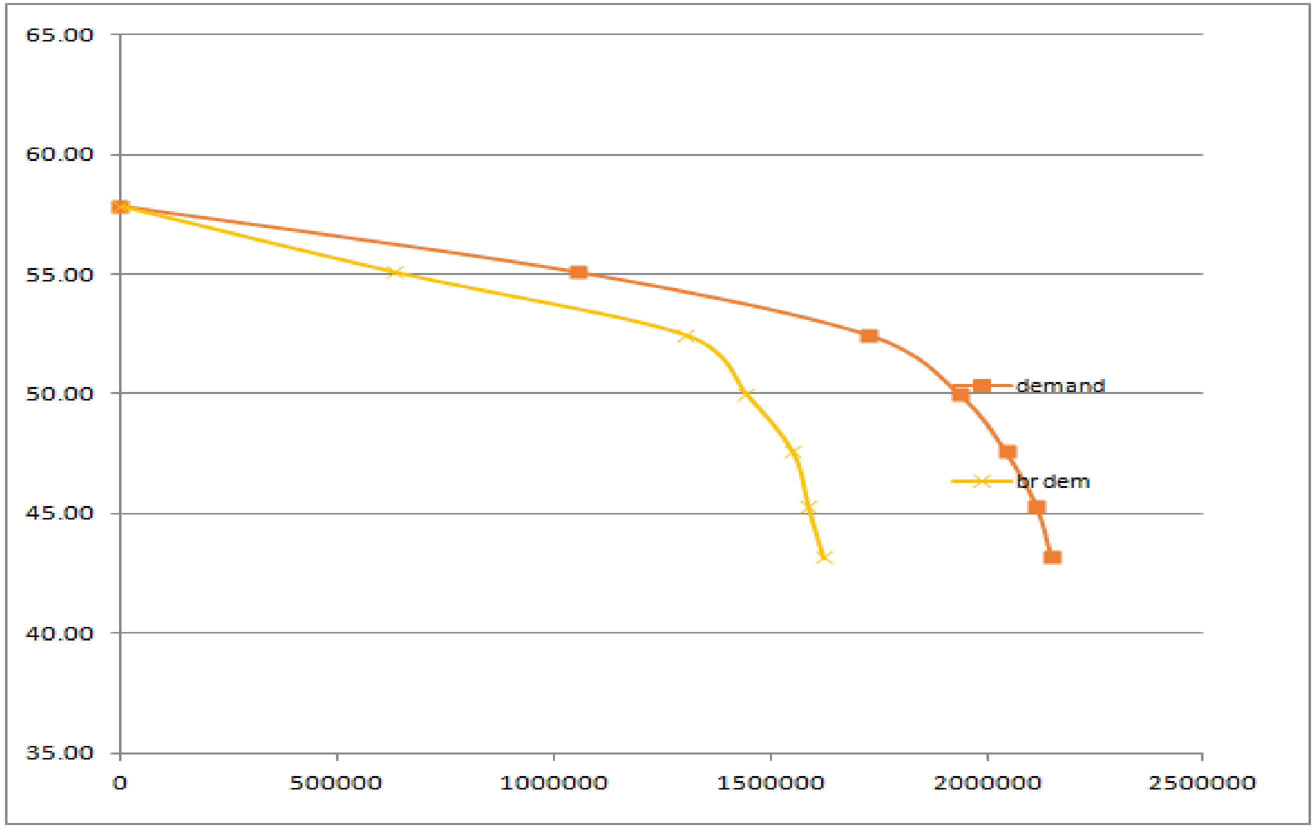
METHODOLOGY (2) THE INDUSTRY MODEL OUTPUT (RESIM)

The industry model generates demand curve

Iterative optimization
driven by decreasing feedstock price
taking into account (increasing) transport
costs.

Both parameters affect the profitability that determines the number of biogas plants by type of technology and size that will be installed



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CASE STUDY: LUBELSKIE REGION

	type of plant	kW	t/year sorghum needed	t/year manure needed	digestate output
Internal Combustion Engine	C1 - ICE	130	**2730**	**8018**	4299.2
	C2 - ICE	250	**5104**	**14990**	8037.6
	C3 - ICE	530	**10252**	**30107**	16143.6
	C4 - ICE	1000	**18608**	**73257**	36746
	C5 - ICE	2000	**35253**	**103531**	55513.6
microgas turbines	C6 - MGT	130	**3675**	**10793**	5787.2
	C7 - MGT	250	**6563**	**19273**	10334.4

- ✓ The regional availability and distribution of Sorghum are provided by the Agricultural Supply Model
- ✓ The regional availability and distribution of manure (technical potential) are provided by census 2010 - holdings headquarters;

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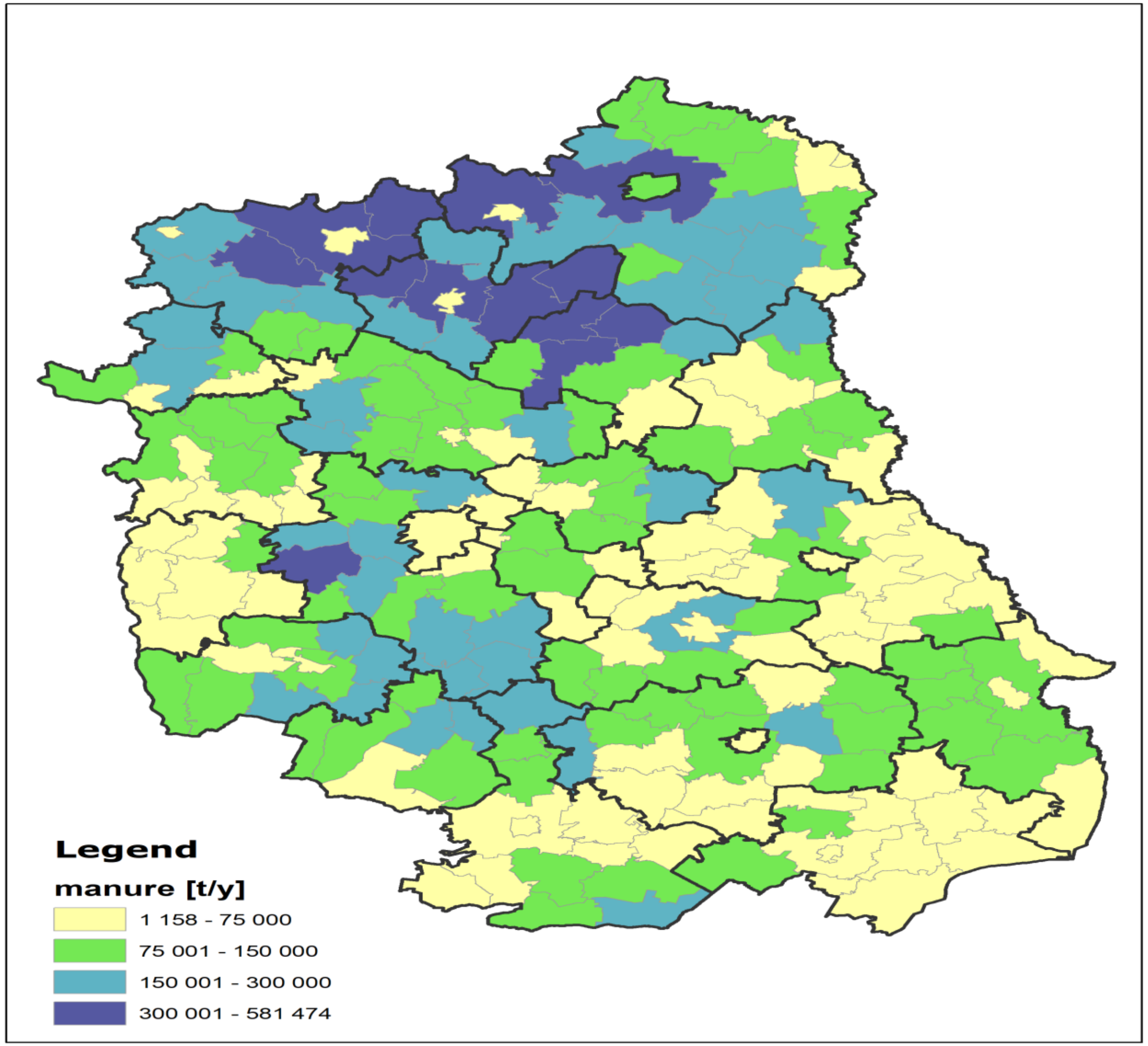
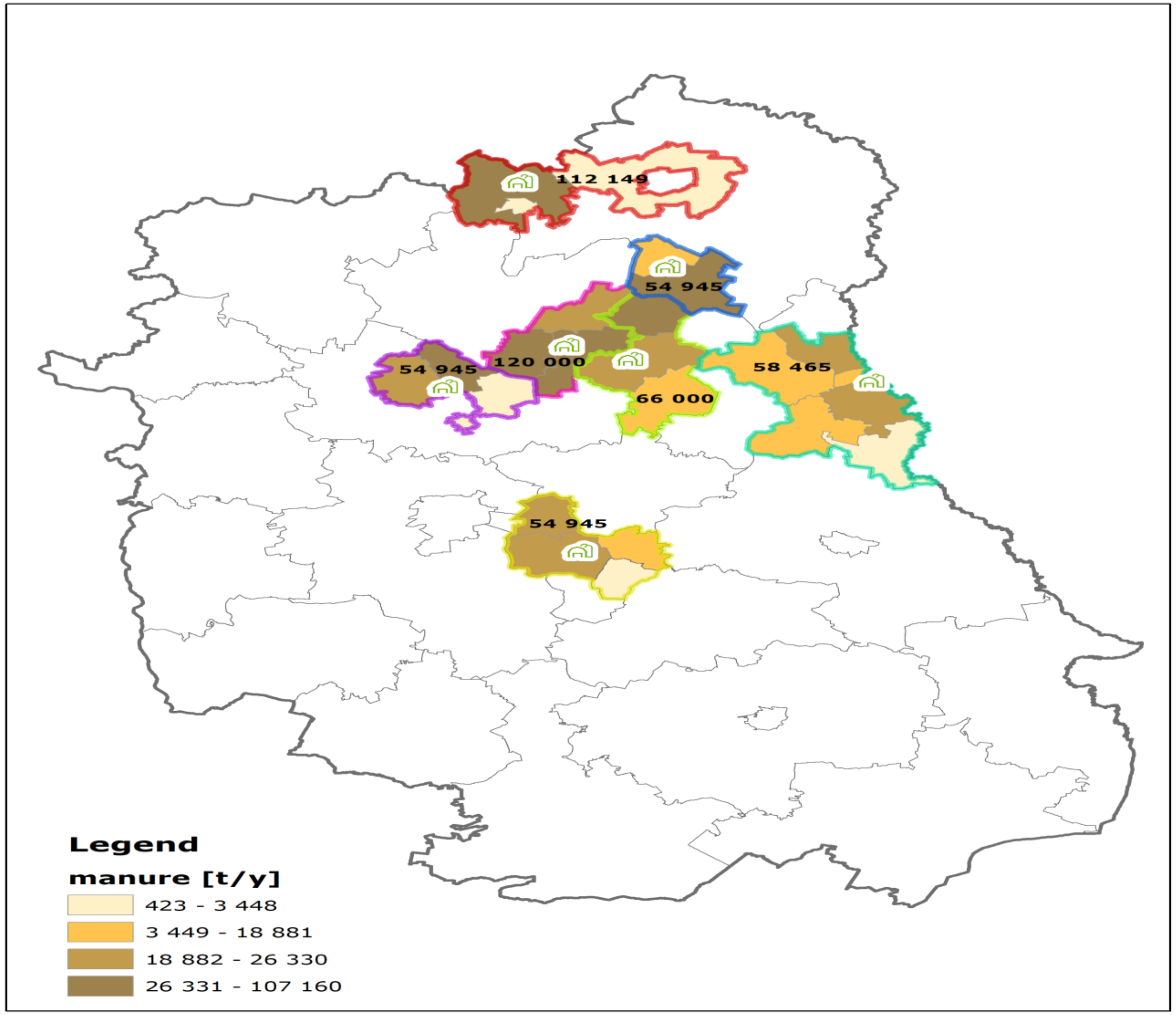
CASE STUDY: LUBELSKIE REGION





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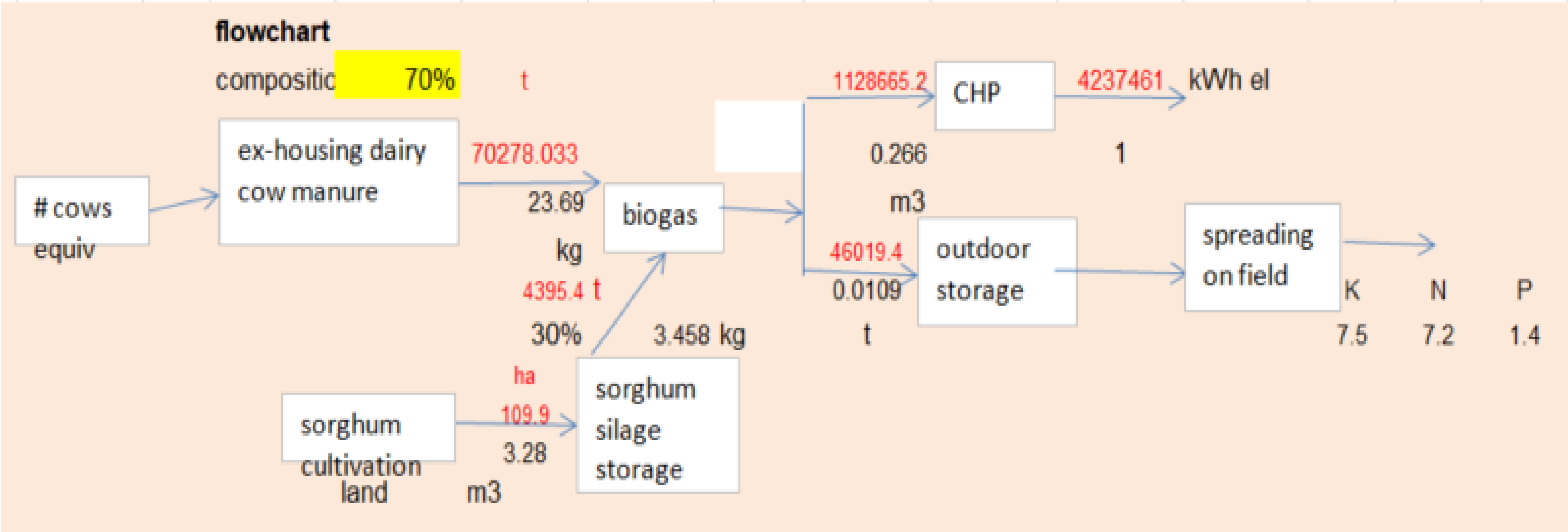
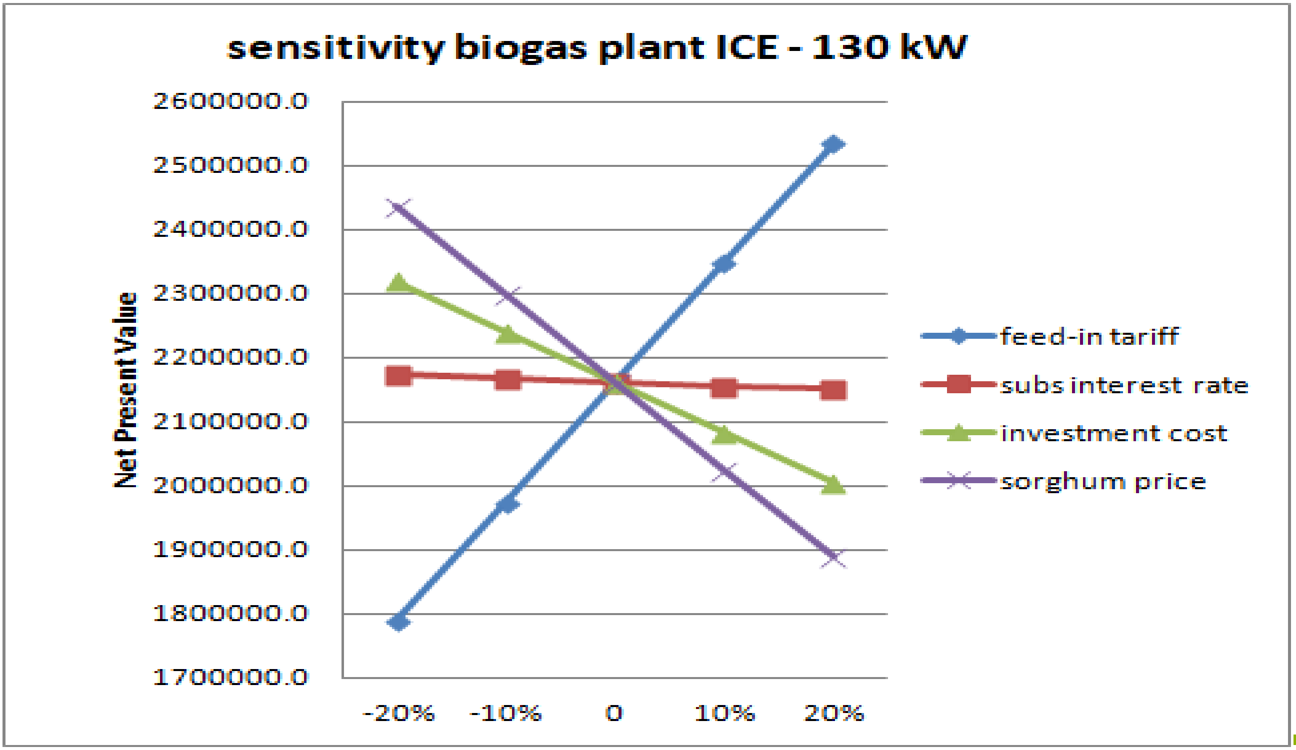
CONVENTIONAL BIOGAS: TECHNOLOGY STATE-OF-THE-ART

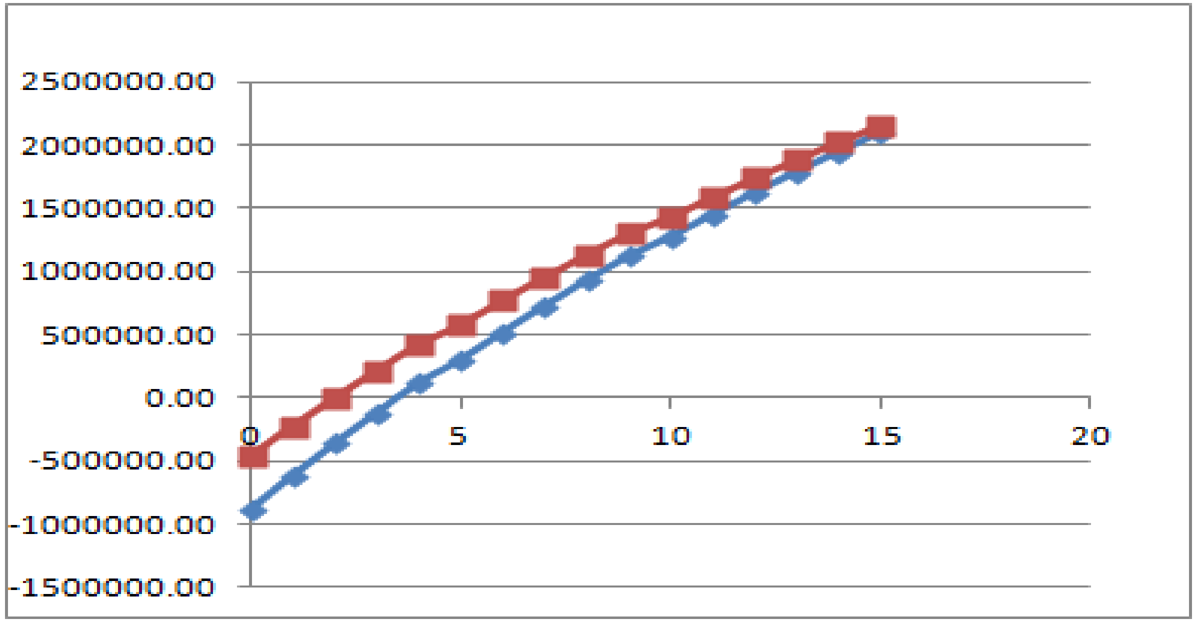


Bartoli, A., Hamelin, L., Rozakis, S., Borzęcka, M., Brandão, M. Coupling economic and GHG emission accounting models to evaluate the sustainability of biogas policies (2019) ***Renewable and Sustainable Energy Reviews***, pp. 133-148.

CASE STUDY: INVESTMENT APPRAISAL

basic info		
electr tariff	0.17	euro/kWh
green	0.0621	euro/kWh
yellow	0.02921	euro/kWh
mauve	0.01357	euro/kWh
thermal energy	0.04	euro/kWh
fertiliser	11.5	euro/ton





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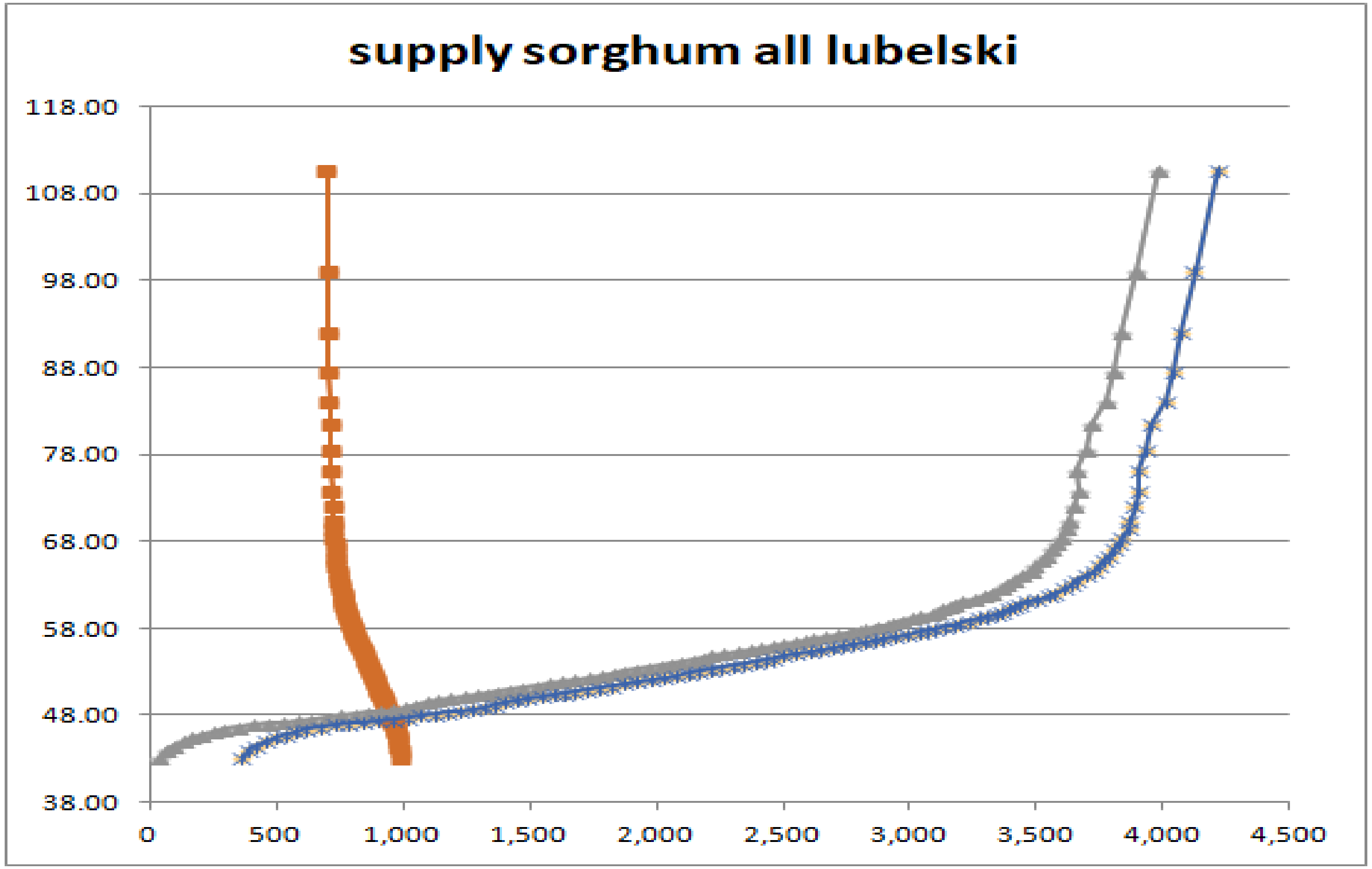
MAIN RESULTS – BIOMASS SUPPLY CURVES



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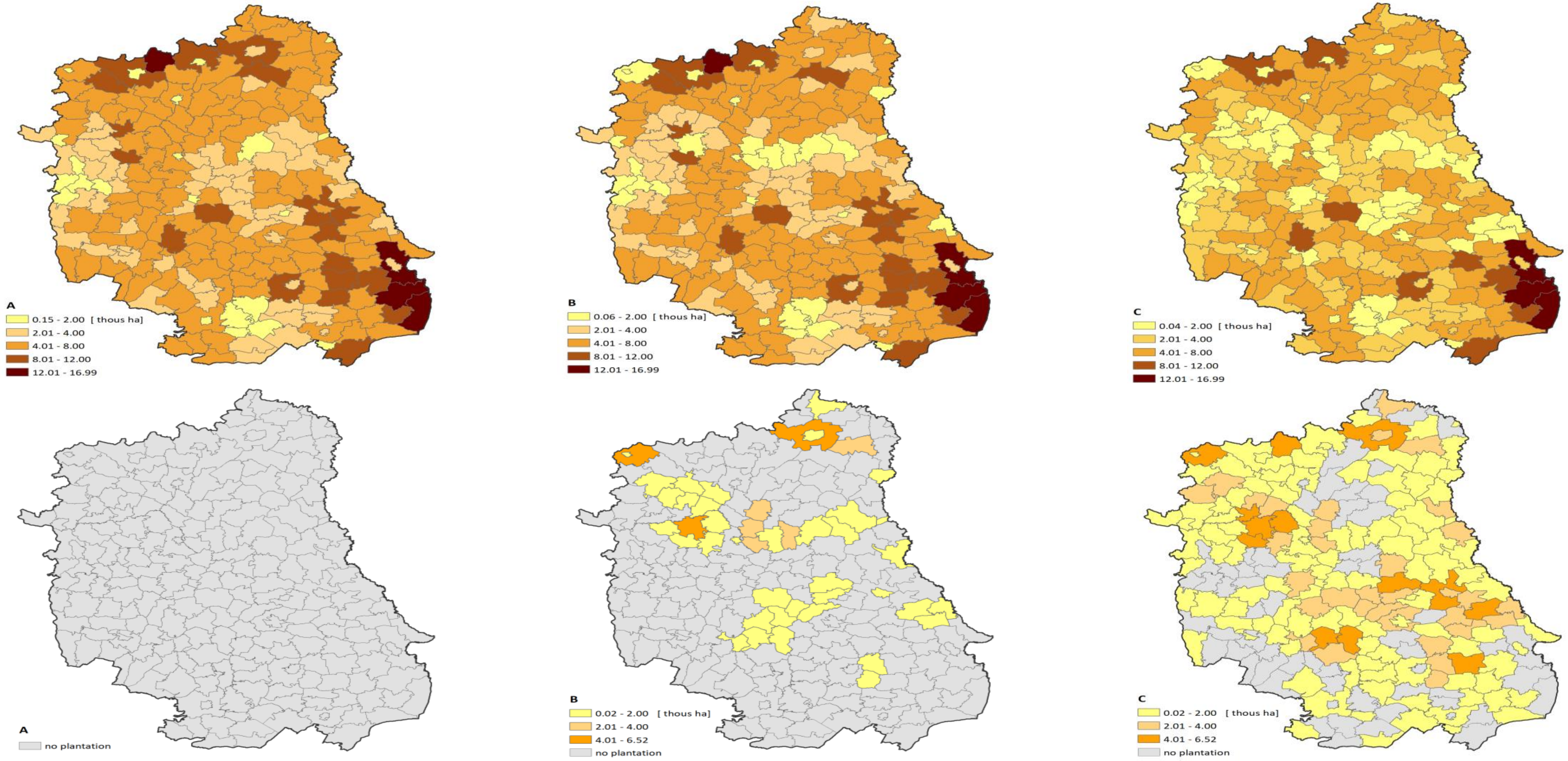
SPATIAL DISTRIBUTION OF BIOMASS SUPPLY



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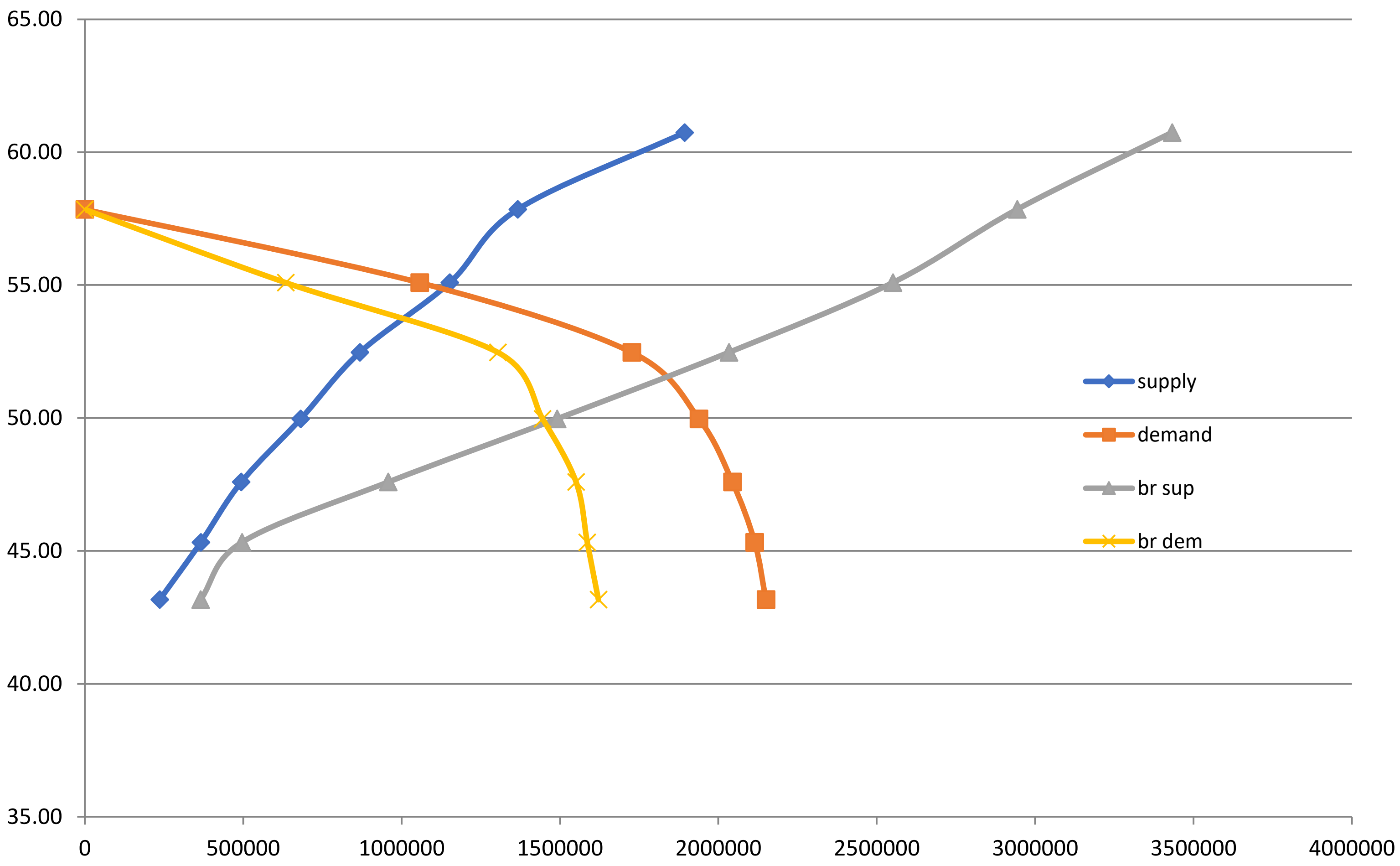
Market equilibrium in two sub-regions



south	p1	23.43 €/t
south	p2	49.60 €/t
south	S	1411392.69 t
south	D	1411392.69 t
# biogas plants		52
Technology		C5
north	p1	45.084 €/t
north	p2	54.25 €/t
north	S	1061939.95 t
north	D	1061939.95 t
# biogas plants		41
Technology		C5

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Conclusions

- **93** Biogas plants allocated at the equilibrium in Lubelskie
- Simulated plants are mainly big-size (**2000 kWe**)
- High demand of biomass for energy (**2.417.000** tons of residues and sorghum)
- Additional land for dedicated energy crops to biogas production (around **15.000 ha**)

→ **Lack of regulations** of raw materials market necessary to generate biogas

→ **Necessity to prompt residues** utilization in order to avoid competition between biogas and food crops

➢ investigate various scenarios (technology progress) and simulate the effects of different regulations for biomass producers in the context of agricultural polices, as well as to evaluate their effectiveness in GHGs reduction (CLCA).

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About me

Edit

Introduction

Operations Research - Multi-criteria Decision Analysis - Decision Support Systems Mathematical programming in agriculture, energy and the environment Economic evaluation of bio-based systems and supply chains Policy analysis - Circular Bioeconomy Strategy

Languages

English · French · Greek, Modern

Bioeconomy and Biosystems Economics Laboratory (BiBELo)

Lab head

Stelios Rozakis

Lab members (2)

Thank you for your attention!