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Report 426

Optimization of the logistics of agricultural biogas plants

Task 4.1 EU-AGRO-BIOGAS

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Abstract

Within the framework of the EU-AGRO-BIOGAS
project, the optimisation model Biolooco has
been adapted for the application on biogas
plants and was applied on a Dutch example
case.

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Optimalisatie van de logistiek bij mestvergistingsinstallaties

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Preface

The research described in this report is a small part of the EU-AGRO-BIOGAS project. This project has been finalised in January 2010. All publishable final reports and deliverables will be published on the project web site: www.eu-agrobiogas.net. The EU-AGRO-BIOGAS project made it possible to implement some improvements in the Biolooco model. These adaptations are described in this report, as well as some results for the EU-AGRO-BIOGAS case.

Samenvatting

Biogas is een belangrijke vorm van duurzame energie, de mogelijkheden zijn onderzocht door een interdisciplinair team met specialisten uit heel Europa in het EU-project EU-AGRO-BIOPAS (<http://www.eu-agrobiogas.net>).

Het optimalisatiemodel Bioloco is ontwikkeld om beleidsmakers te helpen bij de evaluatie van plannen voor biomassalogistiek. Bioloco was beperkt tot de logistiek bij de productie van energie uit biomassa. De laatste tijd komt het gebruik van biomassa bij vergisting en bioraffinage meer in de belangstelling. Daarvoor is het gewenst om ook andere conversietechnieken in Bioloco mogelijk te maken. Bioloco is aangepast, in het EU-AGRO-BIOPAS project, om dit mogelijk te maken. Hiervoor waren aanpassen nodig in de database van Bioloco en in het optimalisatiemodel. The aanpassingen waren vooral gericht op twee onderwerpen: productie van andere producten (dan elektriciteit en warmte) in biomassacentrales en de toevoeging van andere materialen (bijv. maïs in een co-vergister).

De nieuwe versie van Bioloco is uitgetest op een kleinschalige case uit het EU-AGRO-BIOPAS project, een anaerobe vergister die gevoed wordt met rundermest en verschillende co-producten. De resultaten laten zien dat de uitkomsten overeenkomen met de praktijkcijfers, de vergister is rendabel (onder de gegeven veronderstellingen) en de kosten van de co-producten zijn een belangrijke kostenpost. De inputgegevens moeten aangevuld worden om complete resultaten te krijgen.

Summary

Biogas is a key technology for the sustainable supply of renewable energy. EU-AGRO-BIOGAS brings together an interdisciplinary team of leading biogas experts from all over Europe (<http://www.eu-agrobiogas.net>).

The optimisation model Bioloco has been developed to help decision makers to evaluate plans for biomass logistics. Bioloco only included the logistics for energy production from biomass. Recently the role of the use of biomass for digestion, biorefinery and other purposes has increased. This implies a need to include other conversion techniques in Bioloco. Within the EU-AGRO-Biogas project, Bioloco has been adapted to include these possibilities. Modifications in the Bioloco database and in the optimization model were implemented to realize this. The model adaptations in Bioloco are mainly focused on two elements: production of other products (than electricity and heat) in plants and the addition of other materials (e.g. maize in a co-digester).

The new version of the Bioloco model has been tested on a small-scale case from the EU-AGRO-BIOGAS project, an anaerobic digester fed with dairy with manure and several additives. The results show that the model outcomes are in accordance with the practical findings, the digester is profitable (under the given assumptions) and the costs of additives are a major cost component. The input data should be made complete to get complete results.

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1 Introduction

1.1 The EU-AGRO-BIOGAS project

Biogas is a key technology for the sustainable supply of renewable energy. It offers a high flexibility in substrates thus avoiding food-feed competition. Biogas is an essential part in the transition towards integrated biorefinery concepts. EU-AGRO-BIOGAS brings together an interdisciplinary team of leading biogas experts from all over Europe. Leading universities are cooperating with key industry players in order to work towards a sustainable Europe (<http://www.eu-agrobiogas.net>).

Work package 4 of the EU-AGRO-BIOGAS project is involved with the technical process optimization. One of the items in Task 4.1, "Optimization of substrate (regional- and plant-specific measures)", is the optimal design on the regional level on the logistics of the harvested energy crops. As described in the Description of Work, The costs of the logistics of the biomass collection may determine a major part of the feasibility of medium to large scale anaerobic digestion plants. The logistics are often complex and can be set up in many different ways. The logistics, including harvest, storage, pre-treatments, and transport from source locations to the biogas plant will be modelled by means of a network structure. Nodes correspond with source locations, collection sites, transshipment sites, pre-treatment sites or the energy plant and arcs correspond with transport. For this research logistical simulation and optimization models and tools are available (such as Biologics and Bioloco).

The computer model Bioloco has been adapted for the application on biogas plants and applied on a Dutch example case. A general description of Bioloco is given in the following paragraph. The model adaptations are described in the material and methods chapter, the application in the results chapter.

1.2 The Bioloco model

The supply chain of biomass consists of the following components (Diekema et al., 2005):

- Sources of biomass, like residues of the agriculture and horticulture; residues of the food industry; import and multi-functional cultivation.
- Harvesting, when necessary.
- Drying and storage of biomass.
- Pre-treatments of biomass, like size reduction and volume reduction.
- Transport of biomass from the origin to storage and to the power plant.
- Energy conversion, in a plant the biomass will be converted into energy.

The optimal choice of a biomass type, type of power plant, locations, transport, storage and pre-treatments is difficult to make. Before a project can be started, these choices have to be made. Project managers want to make an optimal choice for their specific situation. Optimisation is the process of finding the best way of using resources, at the same time not violating any of the constraints that are imposed. The "best way" can be the one with the highest profit or the lowest cost. In the case of biomass logistics, both financial and energetic goals apply. The returns should be enough to cover the costs and the energy use for the logistics should be much lower than the energy returns in the plant.

To support these choices, the optimisation model Bioloco has been developed. Bioloco helps decision makers to evaluate plans for biomass logistics. Bioloco is an acronym of Biomass Logistics Computer Optimisation. Bioloco was developed by Wageningen University and Research Centre together with Kema by order of EnergieNed.

With Bioloco the biomass chain will be designed in an optimal way with respect to one of the chosen criteria. There are nine object functions:

1. Maximize financial revenues: the revenues are calculated over the energy that comes free after conversion in plants.
2. Minimize financial costs: the logistics costs are divided into six kinds of costs: source costs; storage costs; transport costs; loading and unloading costs; pre-treatment costs and conversion costs.
3. Maximize financial profit. The profit is calculated by subtracting the costs from the revenues.
4. Maximize energy returns. The energetic returns are calculated as the net energy returns in the plants.

5. Minimize energy use. Usages of energy are divided into six kinds of energy consumption: at the sources; for storage; for transport; for loading and unloading; for pre-treatment and for conversion.
6. Maximize energy profit. The energetic profit is calculated by subtracting the energy use from the energy returns.
7. Maximize the emission savings: the energy produced from the biomass replaces conventional energy and hence results in savings in greenhouse gas emissions from conventional energy.
8. Minimize the emissions the greenhouse gas emissions due to the activities in the logistic chain are minimized.
9. Maximize the emission profit: the emission profit is calculated by subtracting the emissions from the emission savings.

Bioloco is implemented as a database in MS Access, combined with a graphical interface and an optimisation module. The database contains data about the logistics, about biomass and other technical data. A menu structure is available to work with the forms in the database.

A graphical interface, Bioloco editor, has been developed in Delphi to make it easy for the user to work with a network in Bioloco. The structure of the network is clearly shown in the graphical interface and relevant data for network elements can be edited by clicking on the element. A network must be made in the Bioloco editor for every case that has to be optimised. A network consists of nodes, depots and arcs. A node is a chain link and consists at one or more depots. Every depot contains one biomass type. Depots are connected with each other by arcs; arcs represent the transport between the depots. Different means of transport can be chosen. In Figure 1.1 an example is given of a simple network. This network consists of eight nodes, 13 depots and has ten arcs. In this example there are three pre-treatments indicated by the circles at the beginning or the end of an arc.

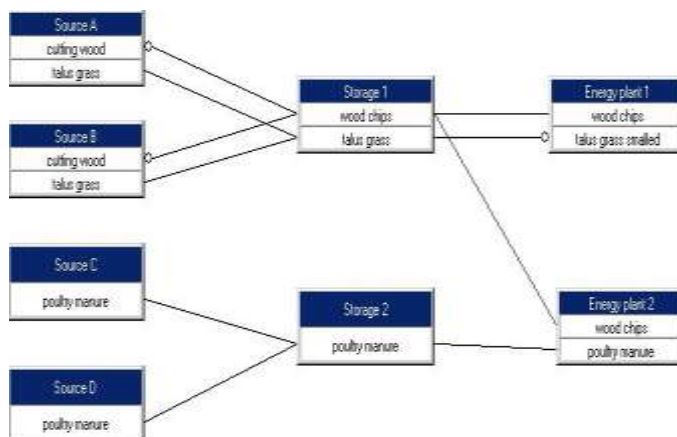


Figure 1.1: Example of a network in the Bioloco editor

When all data for a network are available in Bioloco and an object function is selected, the case can be optimised by the optimisation program Xpress (www.dashoptimization.com). Xpress contains the mathematical model of the logistic chain. The mathematical model of Bioloco model is an optimisation model, which makes use of mixed integer linear programming (MILP). The model Bioloco is taking into account effects that are typical for biomass, like:

- Seasonal fluctuations in supply and demand. Storage is needed to match supply and demand of biomass.
- Moisture losses due to drying: The moisture content of biomass may decrease during storage.
- Dry-matter losses during storage due to biological processes (heating).

Bioloco has been developed in the late nineties of the previous century. It only includes the logistics for energy production from biomass. Recently the role of the use of biomass for digestion, biorefinery and other purposes has increased. This implies a need to include other conversion techniques in Bioloco. In the EU-AGRO-Biogas project, Bioloco has been adapted to include these possibilities and applied for one specific case to demonstrate the new possibilities.

Whenever needed in this document we will make a distinction between:

- *old Bioloco*: the version of Bioloco limited to energy production from biomass;
- *new Bioloco*: the version of Bioloco adapted for digestion, biorefinery and similar processing techniques.

2 Material and methods

2.1 Description of model adaptations in Bioloco

In old Bioloco the biomass logistics from sources to plants is modelled, as well as the conversion of biomass in the plant into electricity, low-valued heat and high-valued heat. The revenues, energy returns and emission savings are based on the payments for electricity and low-valued/high-valued heat. The optimization model is based on a criterion function that is minimized or maximized under certain conditions.

In old Bioloco the criterion functions is composed of one or more the following terms:

1. revenues of electricity, low-valued heat and high-valued heat;
2. costs of purchase, storage, transport, loading/unloading, pretreatment and conversion of biomass;
3. profit: revenues minus costs;
4. energy returns of electricity, low-valued heat and high-valued heat;
5. energy use for purchase, storage, transport, loading/unloading, pretreatment and conversion of biomass;
6. energy profit: energy returns minus energy use;
7. emission savings due to the produced energy, low-valued heat and high-valued heat from biomass
8. emissions due to the energy use for purchase, storage, transport, loading/unloading, pretreatment and conversion of biomass;
9. emission profit: emission savings minus emissions.

In old Bioloco, the criterion function is optimized, by calculation optimal values for variables describing the flows in the network, under the following restrictions:

- a. the criterion terms are composed of all relevant elements;
- b. lower and upper limits for the criterion terms;
- c. supply balance per source and month;
- d. storage balance per depot and month;
- e. volume and weight restrictions for transport;
- f. dry matter, moisture, energetic value and volume in each plant and month is based on flow to the plant;
- g. energy balance per plant and month;
- h. upper limit for moisture content per plant and month;
- i. capacity of plant, for throughput, electricity production and heat production, per plant and month;
- j. relation between electricity production, energetic value and high-valued heat production, per plant and month;
- k. flow to a plant only when plant is opened;
- l. open at least one plant.

Only global descriptions are given here, a detailed definition of the criterion functions and restrictions (in formulas) can be found in the documentation of Bioloco.

The model adaptations in Bioloco are focused on two elements:

- Production of other products in plants: the old Bioloco is restricted to the production of electricity and high-valued/low-valued heat. These products are relevant for energy production plants, for other plants like a digester or a biorefinery, the restriction to these three products is an obstacle. Therefore the definition of production in Bioloco should be more flexible.
- Addition of other materials: this is not relevant in the energy production case, but is essential in other cases. For example, a digester is mostly not only fed with manure but also with other materials like maize (co-digestion). Therefore addition of other materials in case of pretreatment or processing should be possible in Bioloco.

Other model improvements were also included in the update of Bioloco but where not directly related to digester/biorefinery plants.

The inclusion of other product in Bioloco has several consequences:

- Information on the production characteristics should be included in the database, e.g. production factors. The number of products per plant should be flexible.
- Input forms are needed in the database to be able to edit the production characteristics.
- It is preferred that the production characteristics are also editable by the Bioloco editor.
- The variables, criteria and constraints in the MILP model must be adapted.
- The input for the MILP model should include the production characteristics.
- The output from the MILP model should include production data.
- Reports on the production should be available in the database.

It is preferred that the old Bioloco model (with three predefined products) should be part of the new Bioloco model as a special case.

The inclusion of additives in Bioloco also has several consequences:

- Characteristics on the additives should be included in the database, e.g. addition fractions.
- Input forms are needed in the database to be able to edit the characteristics of the additives.
- The variables, criteria and constraints in the MILP model must be adapted.
- The input for the MILP model should include the characteristics of the additives.
- The output from the MILP model should include addition data.
- Reports on the addition should be available in the database.

2.2 Implementation of model adaptations

The inclusion of a more flexible production and additives has several consequences for all parts of the Bioloco software. Changes in the databases included:

- New tables:
 - o Production: default values for production characteristics;
 - o ProductionPlant: site-specific data per plant and product: e.g. total demand and demand factors per month;
 - o ProductionConversion: conversion-specific data per product and conversion technique, e.g. production factor, bulk weight of product;
 - o ProductionConversionAddition: conversion-specific data per product, conversion technique and additive, e.g. production factor;
 - o Additive: default values for addition characteristics;
 - o AdditiveConversion: conversion-specific data per additive and conversion technique, e.g. addition fraction;
 - o AdditivePretreatment: pretreatment-specific data per additive and pretreatment technique, e.g. addition fraction.
- New forms to be able to edit the production and addition data.
- New queries to transfer the production and addition data to the optimization model.
- New reports for the results on production and addition.

The optimization model was also adapted. In new Bioloco the criterion functions is composed of one or more the following terms (changed or new elements in *italic*):

1. revenues of *all products*;
2. costs of purchase, storage, transport, loading/unloading, pretreatment, *addition* and conversion of biomass;
3. profit: revenues minus costs;
4. energy returns of *all products*;
5. energy use for purchase, storage, transport, loading/unloading, pretreatment, *addition* and conversion of biomass;
6. energy profit: energy returns minus energy use;
7. emission savings due to *all products*;
8. emissions due to the energy use for purchase, storage, transport, loading/unloading, pretreatment, *addition* and conversion of biomass;
9. emission profit: emission savings minus emissions.

In new Bioloco, the criterion function is optimized under the following restrictions:

- a. the criterion terms are composed of all relevant elements (*including those for production/addition*);
- b. lower and upper limits for the criterion terms;
- c. supply balance per source and month;
- d. storage balance per depot and month;
- e. volume and weight restrictions for transport;
- f. dry matter, moisture, energetic value and volume in each plant and month is based on flow to the plant;
- g. energy balance per plant and month;
- h. upper limit for moisture content per plant and month;
- i. capacity of plant, for throughput, ~~electricity production and heat production~~, per plant and month;
- j. ~~relation between electricity production, energetic value and high-valued heat production, per plant and month~~;
- k. flow to a plant only when plant is opened;
- l. open at least one plant;
- m. *mass balance for arcs from one plant to another plant*
- n. *mass balance for pretreatments with the additives included*

Due to practical limitations, the graphical editor has not yet been updated to include addition and production.

3 Results

The Biolooco model has been adapted to make it applicable for other plant types like digesters or biorefineries. In this chapter the application of the new Biolooco on a digester case from the EU-AGRO-BIOGAS project will be treated.

3.1 Model input

Wageningen UR Livestock Research investigates the possibilities of anaerobic digesting of manure and the effects on the environment for the agricultural practice (Biewenga et al. 2009). At the Centre for the Dairy Farming Research at Nij Bosma Zathe the anaerobic digester is used for carrying out detailed research into gas yields of cow manure and maize and mineral composition of the ingoing and outgoing streams. The set-up of the installation is very suitable for comparative research. Future research is aimed at co-digestion of farm crops, excess grass of nature reserves and the use of a fuel cell to produce more electricity per unit biogas.



Figure 3.1 Structure of the "Nij Bosma Zathe" case in the Biolooco editor

The structure of this "Nij Bosma Zathe" case is depicted in Figure 3.1. This graph is copied from the graphical editor in Biolooco. The digester, called 'Digester 2' is fed with manure (dairy slurry and solid dairy manure) and additives, the biogas is the input for a Combined Heat and Power (CHP) plant, where the biogas is used to produce electricity and heat.

This network has two sources of biomass, in Figure 3.1 denoted as green depots; details are given in Table 3.1.

Table 3.1 Input parameters of the sources in the "Nij Bosma Zathe" case

Node	Biomass type	Annual supply [ton]	dry matter content [%]	Annual supply [ton dm]	Costs [€/ton dm]	Energy use [GJ/ton dm]
Dairy farms	dairy slurry	3620	8	289.6	0.0	0.0
Dairy farms	solid dairy manure	246	25	61.5	0.0	0.0
	total	3866		351.1		

This network has two plants, denoted as Digester 2 and CHP in Figure 3.1; a selection of input parameters is given in Table 3.2.

Table 3.2 Input parameters of the plants in the "Nij Bosma Zathe" case

Node	Biomass type	Products	Additives
Digester 2	mixed manure	digestate, biogas	see Table 3.3
CHP	biogas	electricity, heat	no

The plant 'Digester 2' is not only fed with manure, but also with additives, see Table 3.3 for input parameters. It is assumed that the production factor for biogas is 639.3 m³ biogas/ton dm input for manure and all additives. The production factor for digestate is assumed to be 0.34 ton dm digestate/ton dm input for manure and all additives.

Table 3.3 Input parameters of the additives of plant 'Digester 2' in the "Nij Bosma Zathe" case

Additive	Annual supply [ton]	dry matter content [%]	Annual supply [ton dm]	Costs [€/ton dm]
maize silage (own production)	246	26	64.0	0.0
grass silage (own production)	530	27	143.1	123.08
maize silage (purchased)	737	26	191.6	123.08
cereals residues	644	73	470.1	154.79
potato press residues	819	16	131.0	156.25
onions	156	10	15.6	0.0
melasse	213	28	59.6	214.29
glycerine	334	66	220.4	166.67
total	3679		1295.4	

Transport of manure and biogas is done by pipeline (only fixed costs involved). There are no pretreatments in this case involved.

Some other assumptions for the model input:

- fixed costs per year for the digester are estimated at €47,331,-, these are the reported costs for repairs, spares, maintenance, as well as labour costs, but investment cost are excluded;
- the price for sold electricity is €0.16/kWh, the price for produced heat is zero;
- energy use in the network (and derived emission) is not yet included;
- methane slip is 2% of produced methane, $1 \text{ m}^3 \text{ biogas} = 0,6 \text{ m}^3 \text{ CH}_4$, density of methane is 0.654 kg/m^3 , so methane slip = $0,012 \text{ m}^3 \text{ CH}_4/\text{m}^3 \text{ biogas} = 0,018 \text{ kg/m}^3 \text{ biogas}$;
- costs of application of digestate is €2,50/m³;
- CO₂ emission factor for energy carriers are taken from Vreuls (2004);
- ...

3.2 Model output

The results of Biolooco are stored in the database and presented by reports, an example is given in Figure 3.2 where the global results of the profit maximization are presented for the "Nij Bosma Zathe" case. Other reports (not shown here) presents the flows in the network and other results of Biolooco.

Under the given assumptions, the "Nij Bosma Zathe" case is profitable. But not all budget items, e.g. storage, transport, loading/unloading, are included yet, and the conversion costs may not be complete. The costs for additives are high as they are almost 60% of the returns for electricity. The energy use data are not yet included, but it is expected that these are low compared to the energy returns in this case. The methane slip will have a major influence on the emissions profit (although emissions from energy use are not yet included).

Output Biolooco light: global results

calculation	95	Tuesday, March 30, 2010	11:25:55 AM
network	BosmaZathe		
criterion	3	maximize profit	
model	2	Biolooco light	

Total throughput: [ton dm]	from sources	350
	to plants	1642

Costs: [euro]:

purchase	€ 0
storage	€ 0
transport	€ 0
loading/unloading	€ 0
pretreatment	€ 0
addition	€ 173,820
conversion	€ 47,331
total costs	€ 221,151

Revenues: [euro]:

biogas	€ 0
digestate	€ 17,451-
electricity	€ 297,360
heat	€ 0
total revenues	€ 279,909
profit	€ 58,759

Energy use: [GJ]:

purchase	0
storage	0
transport	0
loading/unloading	0
pretreatment	0
addition	0
conversion	0
total energy use	0

Energy returns: [GJ]:

biogas	0
digestate	0
electricity	6,691
heat	2
total energy returns	6,693
energy profit	6,693

Emissions, existing: [kg CO2-eq.]:

purchase	0
storage	0
transport	0
loading/unloading	0
pretreatment	0
addition	0
conversion	434,700
total emission	434,700

Emissions, avoided: [kg CO2-eq.]:

biogas	0
digestate	0
electricity	497,112
heat	147
total emission savings	497,258
emission profit	62,558

Calculation 95, on 3/30/2010 11:25:55 AM, for network BosmaZathe, criterion 3, model Biolooco light

Produced: 3/30/2010 11:33:10 AM

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Figure 3.2 Example of output report with global results of profit maximization

4 Conclusions

The Bioloco model has been adapted to optimize the logistical chain for the collection of biomass, not only in cases with a conventional energy plant but also in cases with other types of conversion like a digester or biorefinery. Modifications in the Bioloco database and in the optimization model were implemented to realize this. The new version of the Bioloco model has been tested on a small-scale case from the EU-AGRO-BIOGAS project. The results show that the model outcomes are in accordance with the practical findings. The input data should be made complete to get complete results.

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