Technological and Environmental Impacts Evaluation of Biomass and Biofuels' Supply Chain

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✓Modelling of the optimization problem

✓The scope of the mathematical model

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✓Comparative evaluation of biofuels' SC

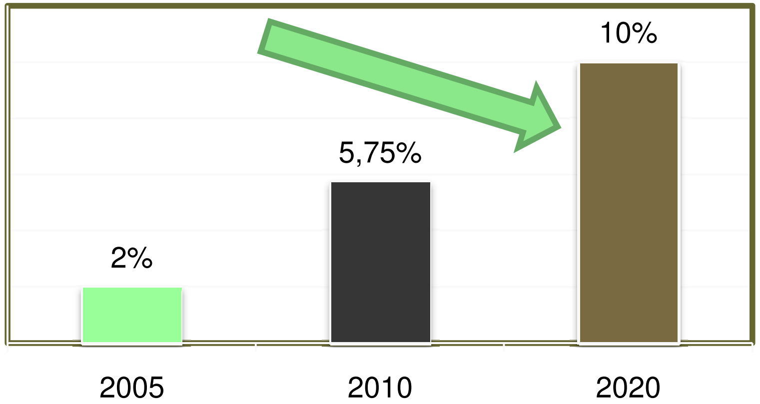
- Conclusions- future prospects

Introduction

- Continuously increasing energy demands
- Rapid growth in population and industrial development
- Depletion of fossil fuel reserves
- Deterioration of the environment / climate change
  - Introduction of alternative fuels (hydrogen, natural gas, biofuels)

Introduction of alternative fuels

Targets set under Directive 2003/30/EC



➢ **Directive 2009/28/EC**

- amends and repeals Directive 2003/30/EC and sets new mandatory national targets by 2020
  - 20% share of energy from RES
  - 10% share of energy from RES in EU transportation energy consumption

Present state situation 1/2

- First Generation (1G) biofuels are mainly produced from edible feedstock from agricultural technologies

Fully commercialized

- Second Generation (2G) biofuels are produced from non edible feedstock from advanced conversion technologies.

Under commercialization

- Third Generation (3G) biofuels are produced from CO_2 neutral feedstock from advanced technologies.

Under development

- Fourth Generation (4G) are produced from CO_2 negative feedstock (emphasis in CO_2 storage).

Present State Situation 2/2

Challenges for biofuels (mainly against 1G) to face
❖ Food or Fuel?
❖ Carbon positive or Carbon negative biofuels?
❖ Environmental friends or eco- enemies?
❖ Energy consuming or energy favorable?

Scope of the work 1/2

- *The scope of the present work is to develop **an integrated approach** of the **whole biomass–biofuels supply chain** and*

➢ *to demonstrate the **main parameters** determining the **technological** and **environmental impacts** of various **generations** of biofuels along with different **production technologies**.*

Scope of the work 2/2

In order to:

- **Reveal the best possible energy mix,**

By taking into consideration :

- **the type and quantities of available raw materials,**
- **the conversion technologies, as well as**
- **the demand side needs.**

Biomass characteristics and uses 1/2

When referring to biomass the basic characterization/nomenclature follows two key principles:

- **the supply side (which types of raw materials are used) and**
- **the demand side (in which type of end – product/ energy it is transformed)**

*Exceptionally for biofuels, the categorization to **1st**, **2nd**, **3rd** and **4th** generation is a bilateral resolution between feedstock and the processing technology.*

Biomass characteristics and uses 2/2

Feedstock/ raw material

- Oil crops (rape, sunflower, etc.), waste oils, animal fats
- Sugar and starch crops
- Lignocellulosic biomass (wood, straw, energy crop, MSW, etc.)Biodegradable MSW, sewage ...rm a...

- Oi... w...
- Sugar and starch crops
- Lignocellulosic biomass (wood, straw, energy crop, MSW, etc.)
- Biodegradable MSW, sewage sludge, manure, wet wastes (farm and food wastes)
- Photosynthetic micro- organisms, e.g microalgae and bacteria

Conversion process/ production technology

- (Biomass upgrading)+ Combustion
- Gasification
  (+ secondary process)
- Pyrolysis
  (+ secondary process)
- Anaerobic ...ing)

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...ation
- Gasification
  (+ secondary process)
- Pyrolysis
  (+ secondary process)
- Anaerobic Digestion
  (+ biogas upgrading)
- Other biological /Chemical routes
- Bio-photochemical routes

End product/ End use

HEAT

and/or

POWER

Syndiesel
Renewable diesel
Methanol
Dimethylether
Hydrogen
Biomethane

Modelling biomass and biofuels SCs 1/2

From simple:

- **Agri –food Supply Chains (SCs),**
- Dealing with production and distribution problems
- **Aiming farmers at decision – making process**
- subsidized farming options, process for crop rotation selection **and/or new machines equipment procurement**

- **With optimization criterion →Profit maximization**
  →Yield maximization

- Multi-biomass (heating cooling and electricity) SC,
- **With optimization criterion →Maximization of NPV of the investment**

Modelling biomass and biofuels SCs 1/2

State-Task-Network (STN) approaches

- **Biomass –to – heat SCs**

→ Optimization criterion: total system cost minimization

➧ Multistage optimization →Biomass to biofuels

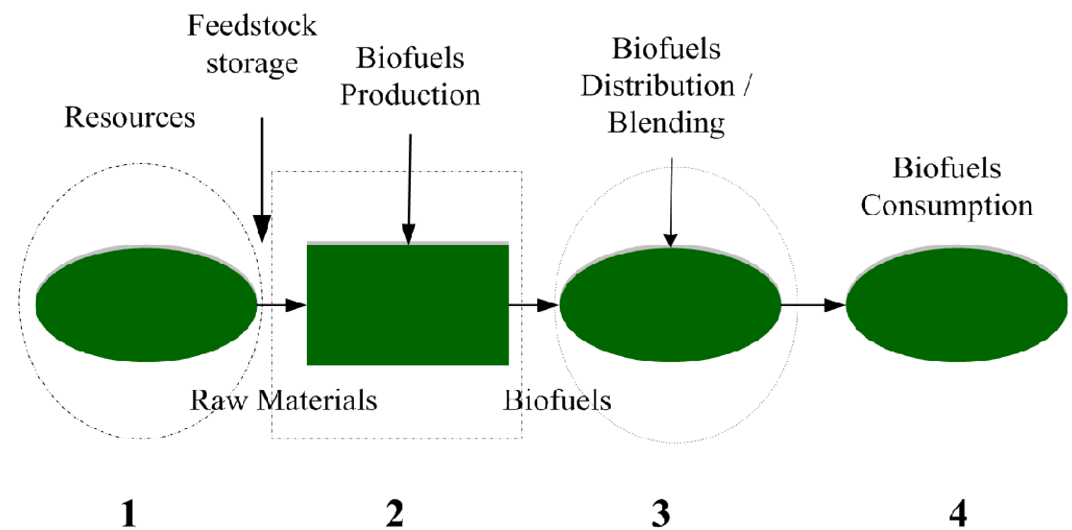
➧Waste biomass-to-energy supply chain management

➧ Carbon footprint optimization of regional biomass

➧ Biomass to biorefineries SC's design and management

Alternative SCs of biomass exploitation

- Raw materials production (which is related to the land availability and suitability, soil's efficiency associated to different types of plants)
- Biofuels production (which refers to the transformation of raw materials through various processes into biofuels)
- Biofuels distribution/Blending (if provided to the end consumers in mixed state)
- Consumption



Biomass to biofuels SC and its characteristics

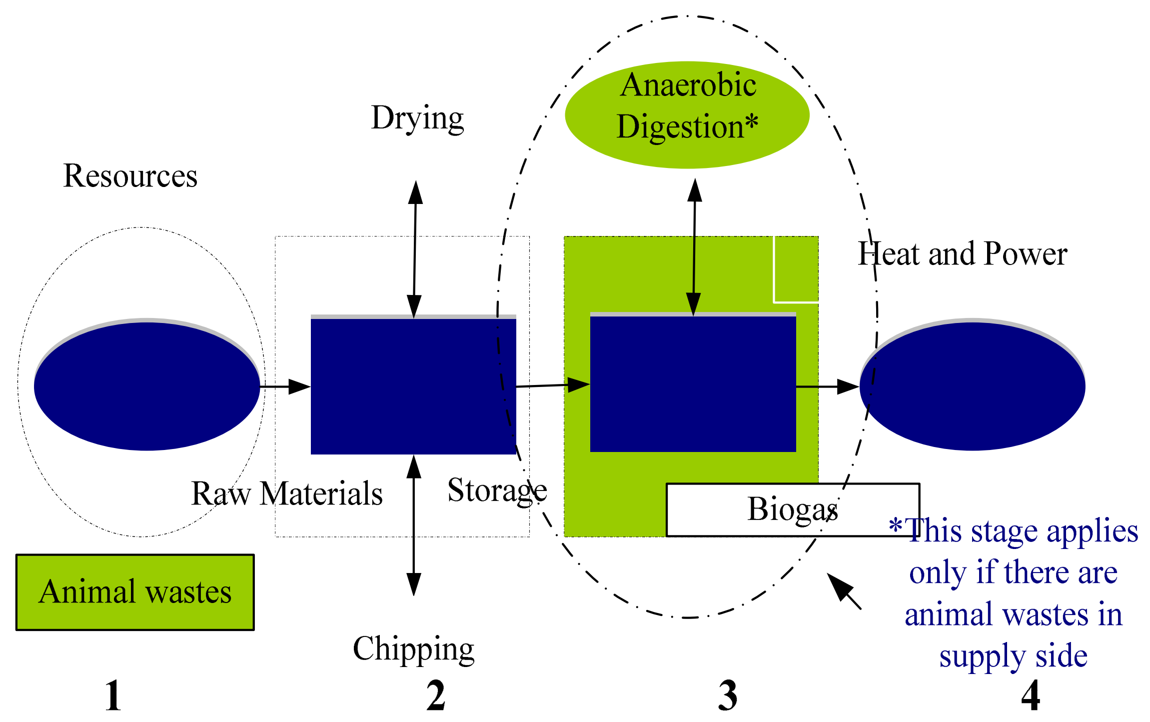
Alternative SCs of biomass exploitation

- Raw materials production (which is related to the land availability and suitability, soil's efficiency associated to different types of plants, or wastes availability)

- Drying and chipping and storage of the processed feedstock

*Digestion to biogas - in the case of animal wastes as feedstock

- Combustion to heat and power



Biomass to heat and power SC with the incorporation of animal wastes input stream and theirs characteristics

Supply chain parameters

- Decision of the point to enter in the supply chain is a strategic issue for policy makers

- The choice of *domestic raw materials' cultivation* is determined by the land availability
- The choice of *domestic biomass' exploitation* is determined by the capacity of national agriculture/ residues
- Energy needs of local character maybe totally covered by biomass optimal exploitation

The scope of the mathematical model

- *Developing a mathematical model for biomass' supply chain contributes to:*

❖ ***Formulating the types of decisions to be made** i.e*

➢ *Shift from operational- local level decisions to strategic – State level decisions about the type and quantities of produced biomass (biofuel-heat-power)*

❖ ***Optimum biomass' supply chain exploitation** i.e.*

➢ *Maximization of the penetration rate of biomass to national energy fuel mix*

Modelling of the optimization problem 1/4

- *The proposed model has the capability to incorporate parametrically a large number of biomass raw materials so as to produce heat, power and biofuels.*
- *The outcome indicates, among other results, which **biomass types** should be chosen and in which **quantities** in order to optimize the total value of the supply chain.*

- **Problem definition**
- *For a given **time horizon***
- *For a set of **selected geographical areas***
- *For a set of **raw materials***

Modelling of the optimization problem 2/4

Optimization criterion

- Maximize the total value (in economic and or energy terms, appropriately defined) deriving from biomass exploitation

Subject to:

Conversion constraints

- Conversion of raw material into heat and or power. The delivered quantity of heat for each raw material is determined by the corresponding conversion factor.

- **Conversion of raw material into biofuels. The delivered quantity of heat for each raw material is determined by the corresponding conversion factor.**

Modelling of the optimization problem 3/4

Availability constraints

- Raw materials availability (residues production capacity, seasonality, animal wastes production capacity).
- **Plants – storage facilities- processing units availability (production capacity, of the existing infrastructures).**

Capacity constraints

- Capacity of the processing facilities.
- **Capacity of the storage facilities. Biomass safety stock for full-load operation.**
- Capacity of the CHP units. The delivered quantity of biofuels is determined by the capacity of the each production plant.
- **Mass balances considering yields in the production units.**

Modelling of the optimization problem 4/4

Energy demand constraints

- **Satisfying the energy demands. The produced energy mix must satisfy the heat, power and transportation demands.**

Variables

- *Raw material produced quantities, facilities siting, creation or not of new infrastructures, end products produced quantities (heat- power- biofuel).*

Parameters

- *Land's availability, feedstock to end product conversion factors, end-fuel production cost in the plants, productions plants' capacities, end products selling prices etc, transportation/logistics costs, environmental (measurable) impacts for each of the selected methods.*

Model indicative outputs 1/2

Selection or not to produce:

- Heat and/or
- Power and/or
- Biofuels

In an optimum mix

- Defined either
- in economic terms (profit maximization) and/or
- in terms of maximum energy yield (maximization of energy output)

For a resulted –selected feedstock set

Model indicative outputs 2/2

- The results from model implementation include the following:
  - **Decision making in investing in domestic raw materials cultivation**
  - **Decision making in investing in which type of biomass production units**
  - **Determination of cultivation and production units sitting**

- ***The main difficulty and the critical factors for the successful model implementation are the reliability and validity of all data being collected and employed.***

Comparative evaluation of biofuels' SC

	Index	Biodiesel 1G	Biodiesel 2G	Bioethanol 1G	Bioethanol 2G
Land	Carbon dept [mg CO_2/ha]	→		→	
	Land utilization [t/ha]	→		→	←
Energy	NEV [E_{output}-E_{input}-$E_{co\text{-}product}$ MJ/l]	→	←	→	←
	Energy balance [MJ biofuel (1lt) / MJ energy consumed]	→		→	
	Gross energy yield [GJ/ha]	→			←
Air-Climate	GHG emissions [g CO_2 eq./ MJ]	→			←
	GHG balance or GHG savings [%]	→		→	
Water	Water consumption [lt H_2O/ lt biofuel]		←	→	
	Eutrophication [kg, P,N/ ha]	→	←	→	
Flora- Fauna	The same indices as water				

Environmental indices per natural source/receiver depending on biofuels' generation

Conclusions 1/2

The **environmental evaluation** of biofuels SC indentified that the most energy-consuming / eco- less friendlier process step is :

Production stage, and the critical parameters incorporated:

- Primary use of land
- External inputs (water, energy, fossil fuels, fertilizers interaction with terrestrial ecosystem)
- GHG emissions

- Possible transition from **1st** to **2nd** generation biofuels maybe identified, if the major energy indices are examined.

Conclusions 2/2

Model outputs

- **Types of raw materials production**
  - **Quantity of raw materials to be processed by the plant**
- **Quantities of final products**
  - **Financial benefits**

- ***Already the model was tested for the prefecture of Thessaloniki, and results were promising.***

Future work should include:

- Model application in similar green energy supply chains
- The inclusion of cost parameters concerning transport issues, environmental issues, sitting themes (GIS incorporation), more complicate economic structures (deprecation issues, investment issues).

Thank you for your attention

- Optimisation of Production Systems Lab

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