Sustainability assessment of biomass-to-energy processing chains scenarios: a necessity for decision makers

D. Lecomte
Professor,
Institut de Technologie du Cambodge

1. The place of bioenergy in climate change mitigation
2. Which bioenergy ?
3. Sustainability assessment of bioenergy pathways

Bioenergy is energy of biological origin, derived from biomass, such as fuelwood, livestock manure, municipal solid waste, energy crops, …

Clean energy in Vietnam after COP21, 17-18 Dec 2015, Hanoi, Vietnam

1. The place of bioenergy in climate change mitigation
   - Emissions from tropical agriculture
   - Options to reduce emissions from agriculture

2. Which bioenergy ?

3. Sustainability assessment of bioenergy pathways

Bioenergy is energy of biological origin, derived from biomass, such as fuelwood, livestock manure, municipal solid waste, energy crops, …

Emissions from tropical agriculture

1. Deforestation for agriculture: carbon stock consumption (soil and biomass)

2. Rice cultivation: source of emissions of 3 main greenhouse gases: methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2)

3. Cattle breeding, source of methane (CH_4)

Source : R Wassmann, P. L. G. Vlek, Mitigating greenhouse gas emissions from tropical agriculture : scope and research priorities

The place of bioenergy in climate change mitigation

Options to reduce emissions from agriculture:

1. Maintain and increase the stock of organic matter in soils and biomass:
    - through better soil management
    - restoring wetlands and degraded lands

2. Reduce the consumption of fossile C:
    - reduce emissions from agriculture
    - **produce alternative fuels from biomass: bionergy**

Source : K Paustian, V. Cole, D. Sauerbeck, CO2 mitigation by agriculture, an overview, Climate Change, 1998, 135-162

The place of bioenergy in climate change mitigation

	C (in Gton/year) Low estimate	C (en Gton/year) Hign estimate
Restauration / preservation of soils	0,4	0,9
Reduction of emissions in the agricultural sector	0,01	0,05
Production of biofuels from agricultural and forestry origin	0,3	1,3
Valorisation of agricultural waste	0,2	0,3

Source : K Paustian, V. Cole, D. Sauerbeck, CO2 mitigation by agriculture, an overview, Climate Change, 1998, 135-162

1. The place of bioenergy in climate change mitigation

2. Which bioenergy ?
   - Resources
   - Biofuels
   - Bioenergy production lines

3. Sustainability assessment of bioenergy production lines

Which bioenergy ?

Resources:

1. Waste and by-products to energy

- Agricultural waste:
  Examples: millet stalks, animal manure, ...

- Waste and by-products from the industry of biomass transformation
  Food, feed, textile, cosmetics, …
  Examples: cotton hulls and stalks, bagasse, rice straw, slaughter waste, shells and palm fiber, soybean meal, peanut shells ...

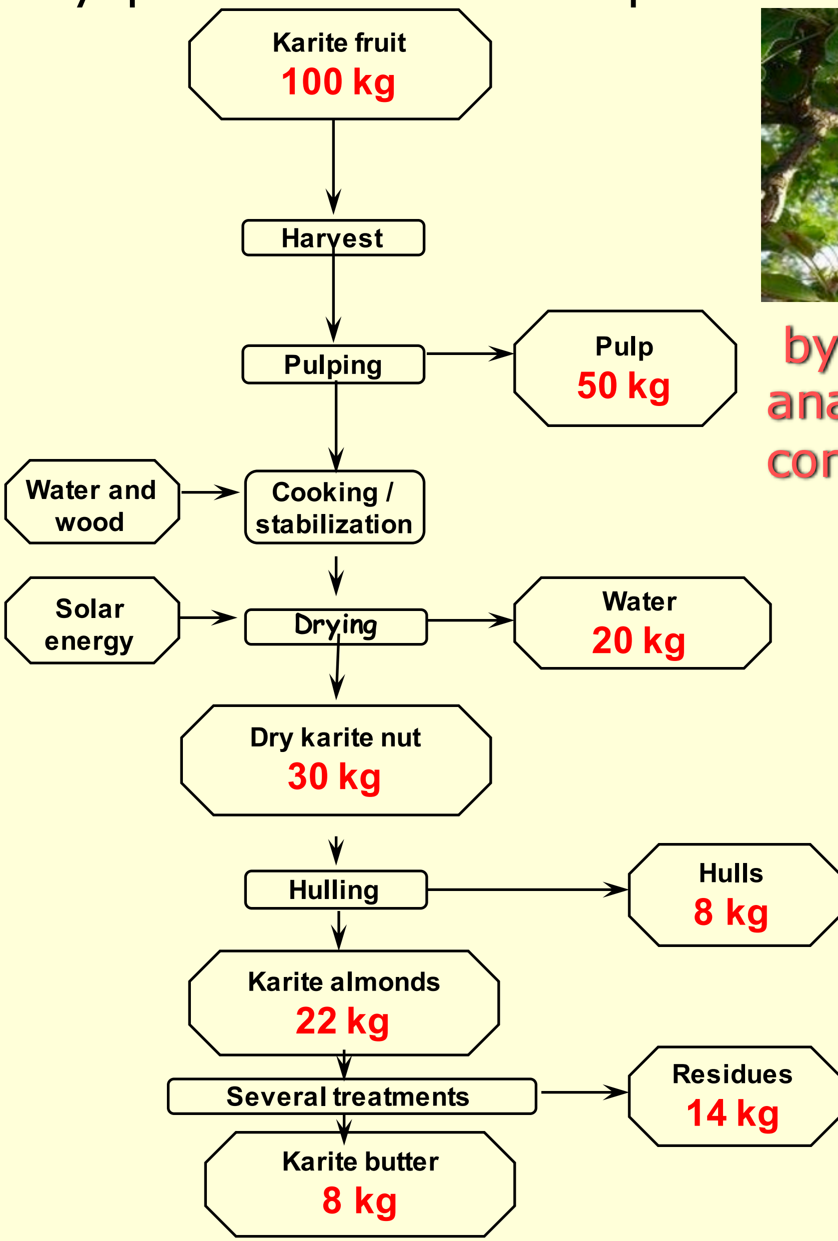
- Urban waste:
  Examples: sewage sludge, fermentable part of household plastics, ..., …

Important moisture content
Waste: mixtures and contamination

Which bioenergy ?

Example : waste and by-products from the processing of karite butter

100 kg fruit =
8 kg butter
+ 92 kg waste
and by-products



by-product -> anaerobic digestion -> combustion

by-product -> combustion

waste -> combustion

Resources:

2. Energy crops and forestry by-products

- Forest management residues -> electricity
  Examples: wood chips, sawdust, pellets,

- Forestry crops -> electricity
  Examples: salix (Northern Europe), poplar, eucalyptus, miscanthus (Africa), reed canary grass

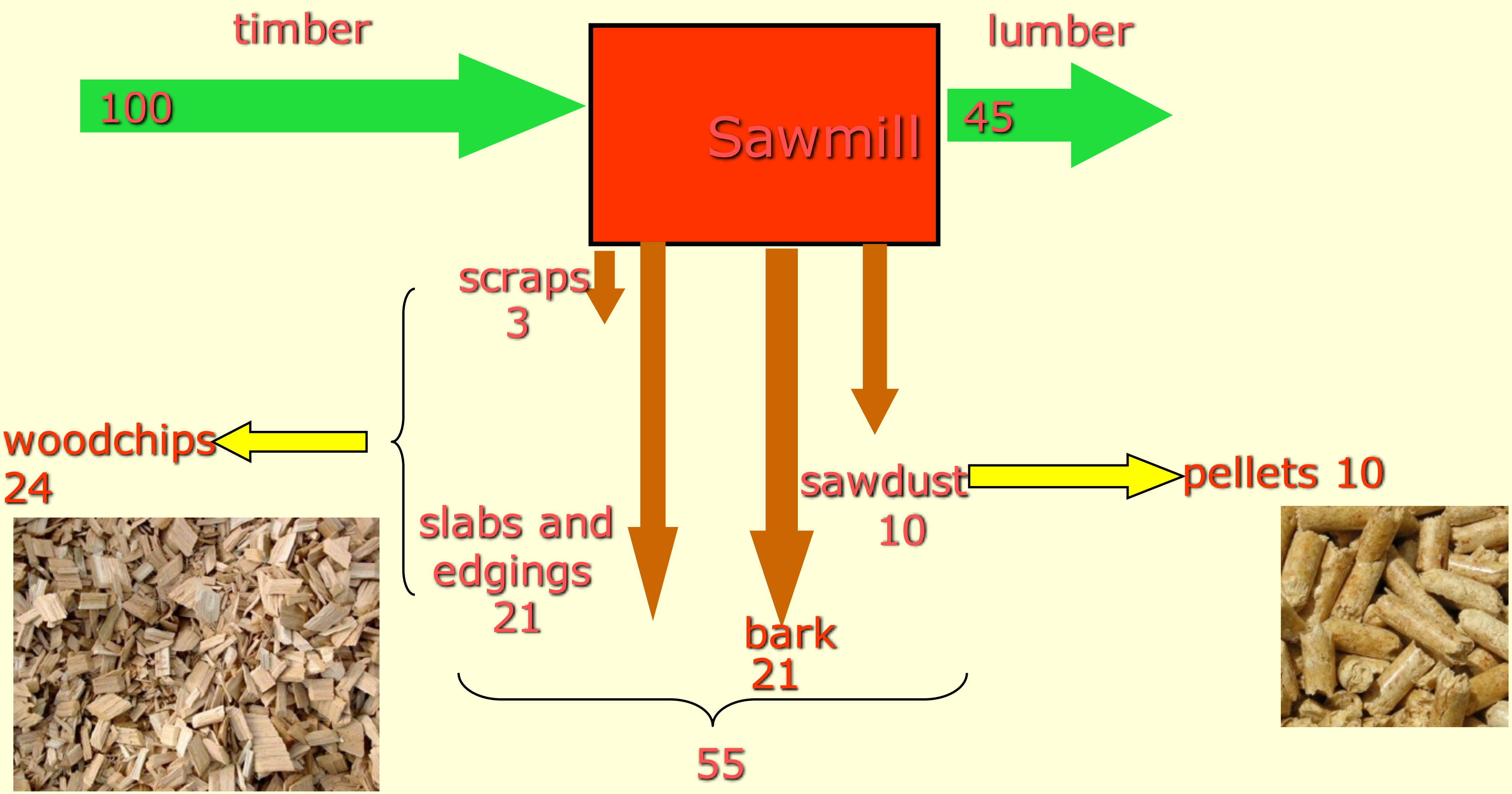
- Oilseeds crops -> biodiesel
  Examples: palm oil (Indonesia, Malaysia), soybean (US), rapeseed (Europe), jatropha (India, Africa)

- Sugar and starch crops - > bioethanol
  Exemple: cereals (US), sugarbeet (Europe), sugar cane (Brazil), cassava (South East Asia)

Which bioenergy ?

By-products from wood processing

Example : sawmill



Biofuels

Solid biofuels

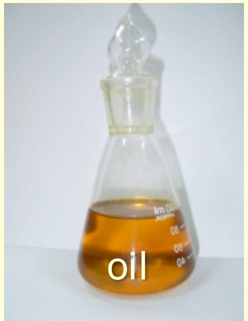
- charcoal produced by partial combustion of wood
- torrefied wood
- wood chips obtained by drying and comminution
- pellets, briquettes obtained by drying, comminution, densification of wood sawdust
- Bagasse bricks obtained by drying and densification,

etc.

Biofuels

Liquid biofuels:

- Pyroligneous liquids (tar, oil, acid) from flash pyrolysis
- Liquids from supercritical liquefaction
- Black liquor (a by-product of pulp and paper industry)
- Methanol / ethanol (hydrolysis - fermentation)
- Methanol (reforming)
- Oil (oilseeds transformation, recycled oils)
- Biodiesel (Methyl Esther, Fischer-Tropsch process)



Typical black liquor analysis

Agent	Content [g/kg dry solid]
Na	19.3
K	3.34
S_{tot}	5.50
Cl_{tot}	0.41
S^{2-}	1.93
NaOH	1.1
CO_3^{2-}	6.2
Na_2SO_3	0.1
$Na_2S_2O_3$	2.13
Na_2SO_4	1.23
C	31.9
H	3.33
N	0.08

Calorimetric heat value, HHV 12.74 (MJ/kg dry solids)

Which bioenergy ?

Biofuels

Gaseous biofuels:

- Mixture of gases from anaerobic digestion (biogas)
- Mixture of gases from high-temperature thermochemical conversion (SynGas)

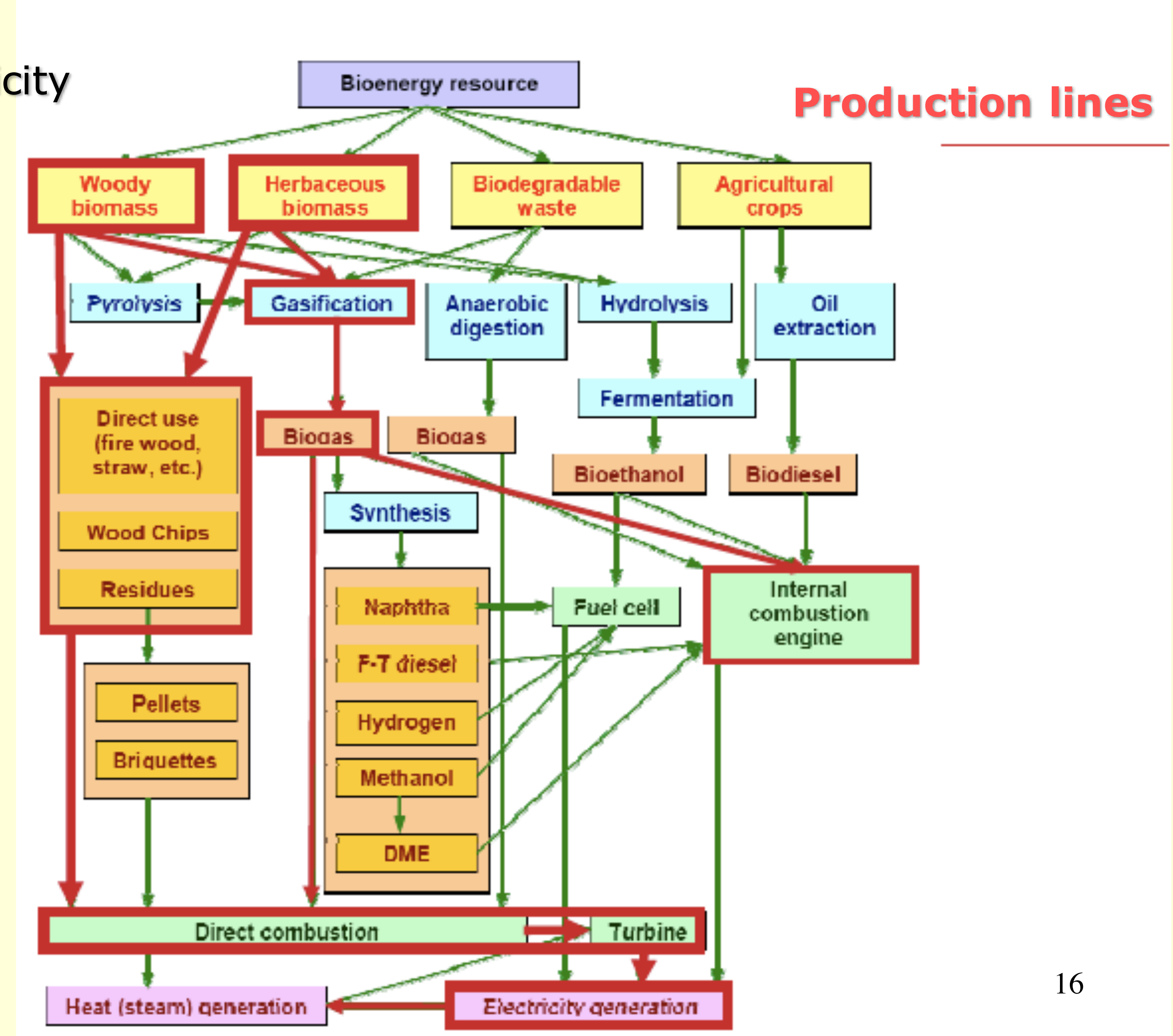
Main biofuel gas: hydrogen (H_2), carbon monoxide (CO), methane (CH_4), light hydrocarbons in admixture with nitrogen (N_2)

Bioenergy production lines

- Different types of energies : heat, steam (heat and work), electricity (work)
- **Heat, steam and electricity** are intensively used in industry
- Industrial processes need **heat at a specific temperature level** which can be obtained by combustion of biofuels: metals, glass, glaze, ceramics, plastics, …
- **Production lines** from waste and biomass:
  - Waste or crop -> biofuel -> heat
  - Waste or crop -> biofuel -> electricity
  - Waste or crop -> biofuel -> heat and electricity

Which bioenergy ?

Steam and Electricity generation



Which bioenergy ?

Bioenergy production lines

Many steps, many options

- Growth: type of crop, type of agriculture
- Harvest: crops, wood
- Collection: crops, wood residues, waste
- Transport : crops, wood residues, waste
- Sorting: waste
- Transformations : chemical, thermal, mechanical, biochemical
- Transport : biofuels
- Conversion : heat, steam, electricity

Which bioenergy ?

Bioenergy production lines

Many issues are raised at each step of the production line

- Technical issues due to the processing of complex products (ex: slags, chorine)
- Production line efficiency : mass, energy (water content)
- Availability of resource : soil, climate, market price
- Competition on use: land, food, feed, chemicals, materials, …
- Environmental: biodiversity, pollution, health, soil erosion, …
- Economical: market price, value added creation, …
- Social: social organization, adaptation to change, local human resources management

The best option is the most sustainable option:

- technically and economically viable,
- environmentally sound
- socially responsible

1. The place of bioenergy in climate change mitigation

2. Which bioenergy ?

3. Sustainability assessment of bioenergy production lines
   - Which assessment ?
   - Special focus: life cycle assesssment
   - Example 1: sludge to energy: a new process
   - Example 2: biofuel in Burkina Faso

Bioenergy production lines

- **Which assessment ?**

There is an infinite set of **technical options** to set up and maintain a production line.
Because of the capital cost involved, bioenergy production lines need precise investigations:

- **Estimation** of the potential or actual **resource** of the biomass: **quantitative** and **qualitative**
- actual **feedback** on existing plants: mass, energy and economical balance, environmental assessment
- updated information on **best available technologies** (BAT) for energy efficiency and emissions
- full preliminary **environmental assessment of emissions** for comparison of options on a life cycle base
- Evaluation of **socio-economic** impact or different options

Bioenergy production lines

- **Sustainability assessment:**

This is an important and difficult research field because of:

- The number of disciplines involved: geography, agronomy, economics, sociology, engineering, environmental sciences, biological sciences…
- The lack of information on technical performances of equipment
- The lack of information on environmental impact : esp. health or biodiversity

2 examples are given, derived from 3 PhD works under my supervision between 2002 and 2014**.**

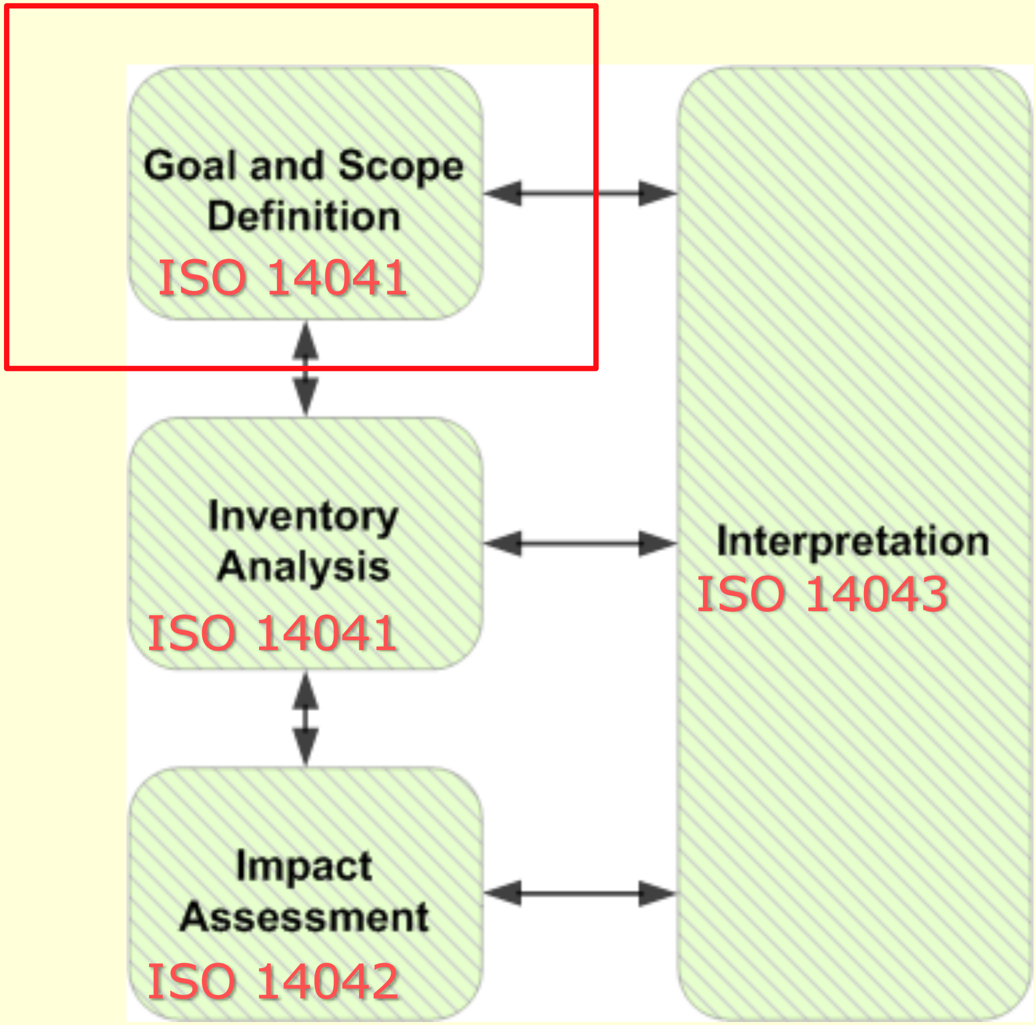
A focus on Life Cycle Assessment (LCA)

From craddle…
… to grave

The goal of LCA is to compare the full range of environmental and social damages assignable to products and services, to be able to choose the more sustainable one

- Standard ISO 14041-43

Four distinct phases



Sustainability assessment of bioenergy production lines

Example 1: Life cycle inventory to design fry-drying process of industrial biomass

Fry-drying concept

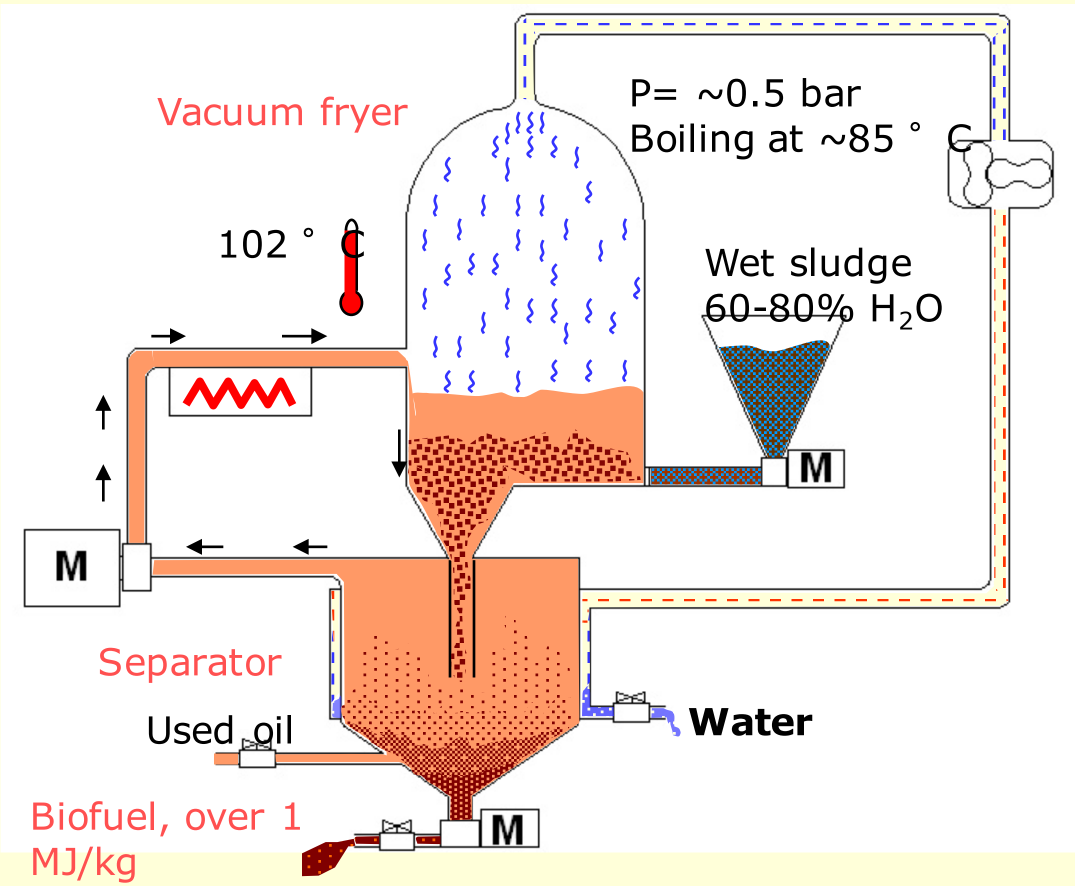
Recycled cooking oils

Sludge

Sterile fuel
Granular solid

PhD works,
C. Peregrina-Cambero and
MH Romdhana, Mines Albi

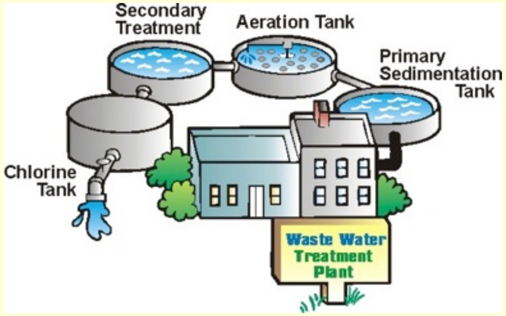
Fry-drying concept with energy recovery



PhD work, MH Romdhana, Mines Albi

Sustainability assessment of bioenergy production lines

Goal and scope definition : functional unit (ISO 14041)



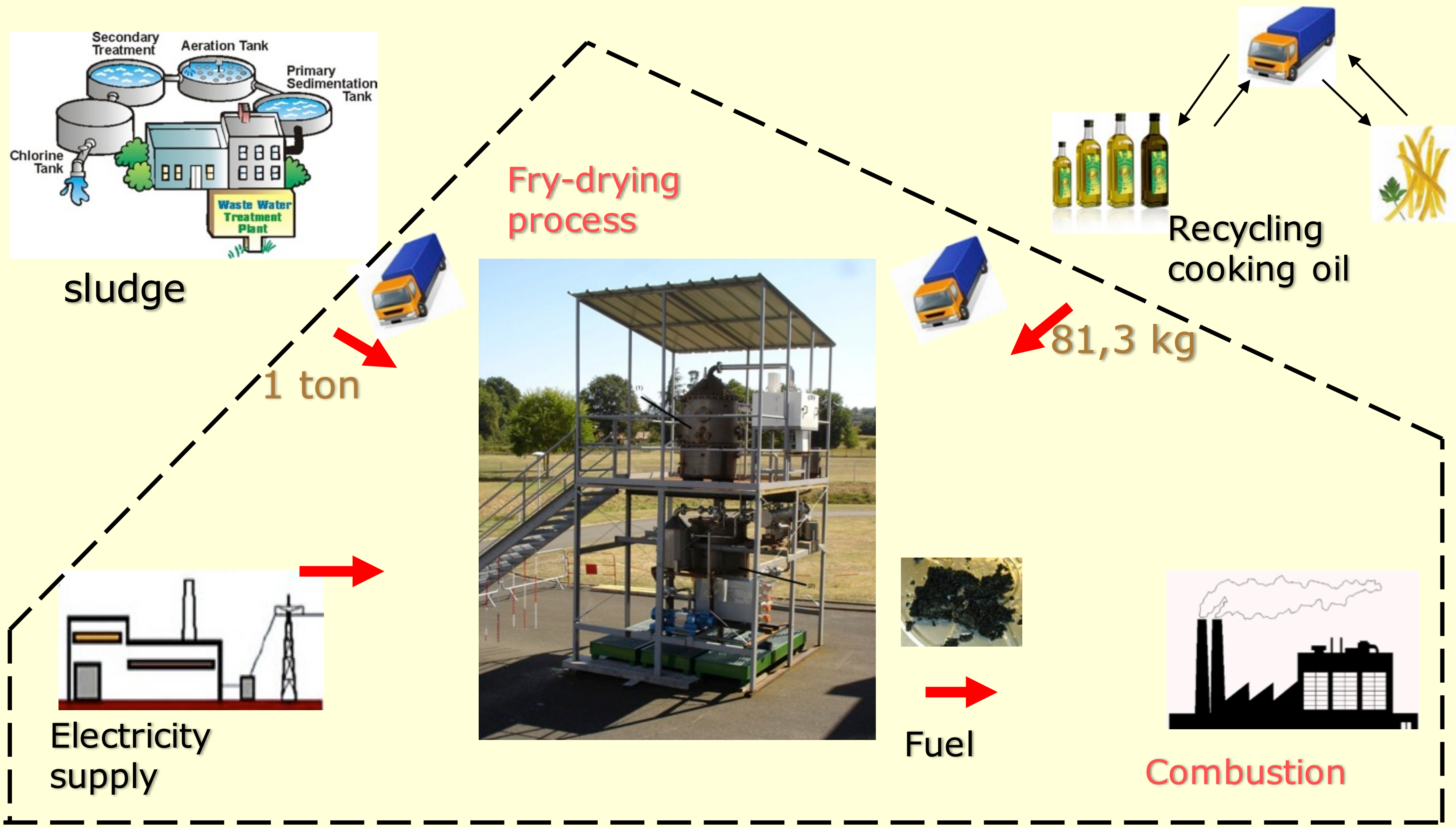
1 ton

81.3 kg

Functional unit: simultaneously processing 1 ton of wet sludge (60% moisture content) and 81.3 kg of recycled cooking oil

Life-cycle assessment: boundaries

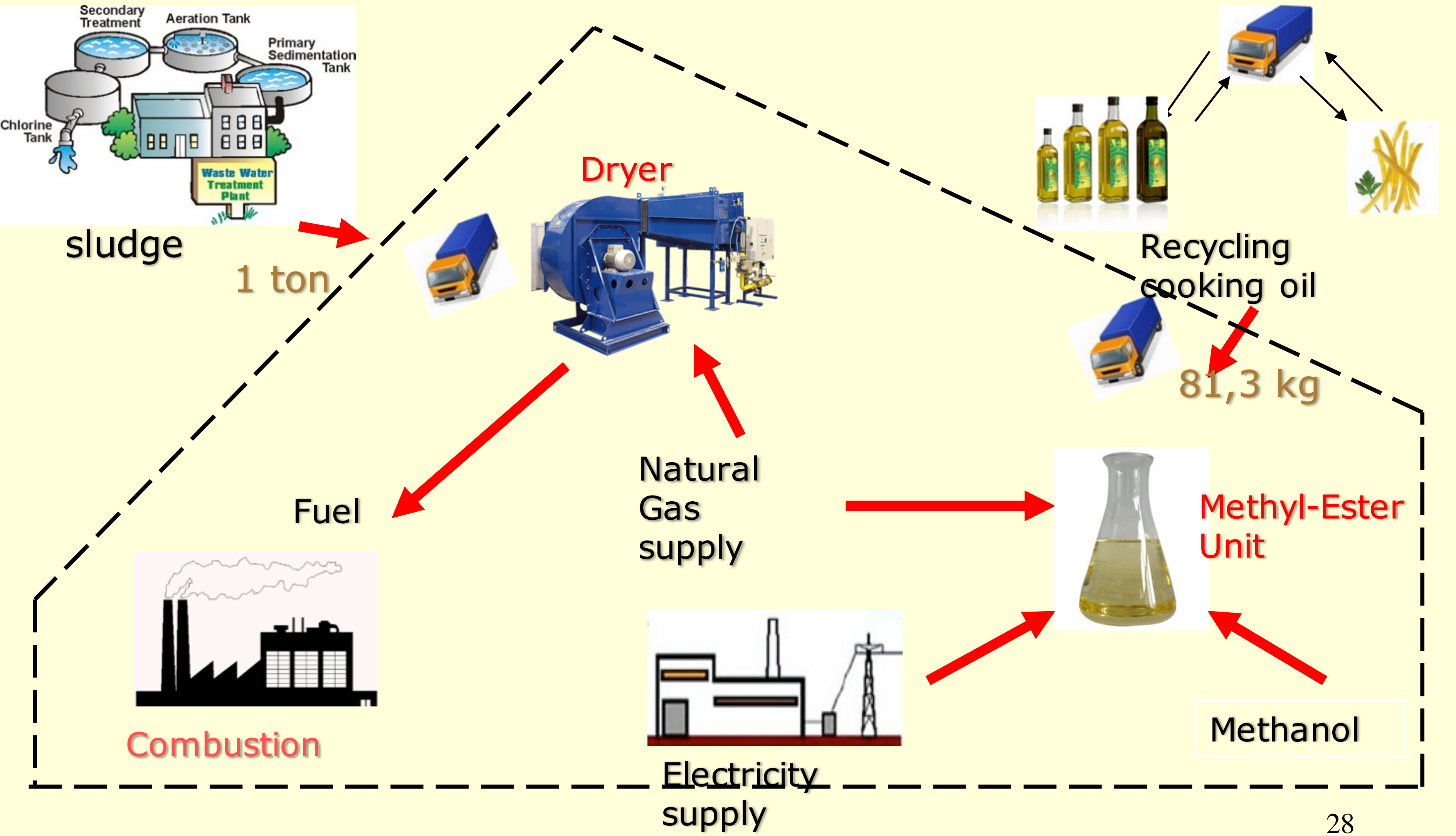
Goal and scope definition : boundaries (ISO 14041)



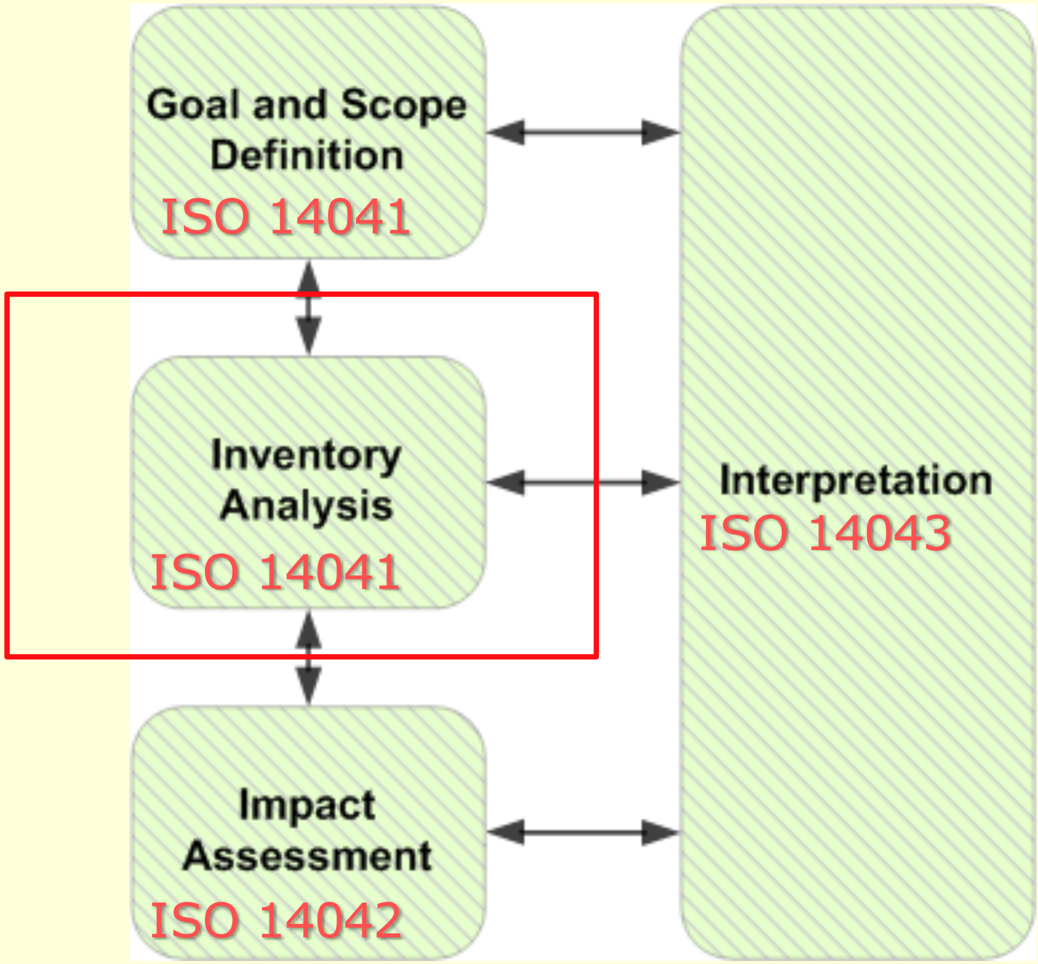
Life-cycle assessment: boundaries

Goal and scope definition : boundaries (ISO 14041)

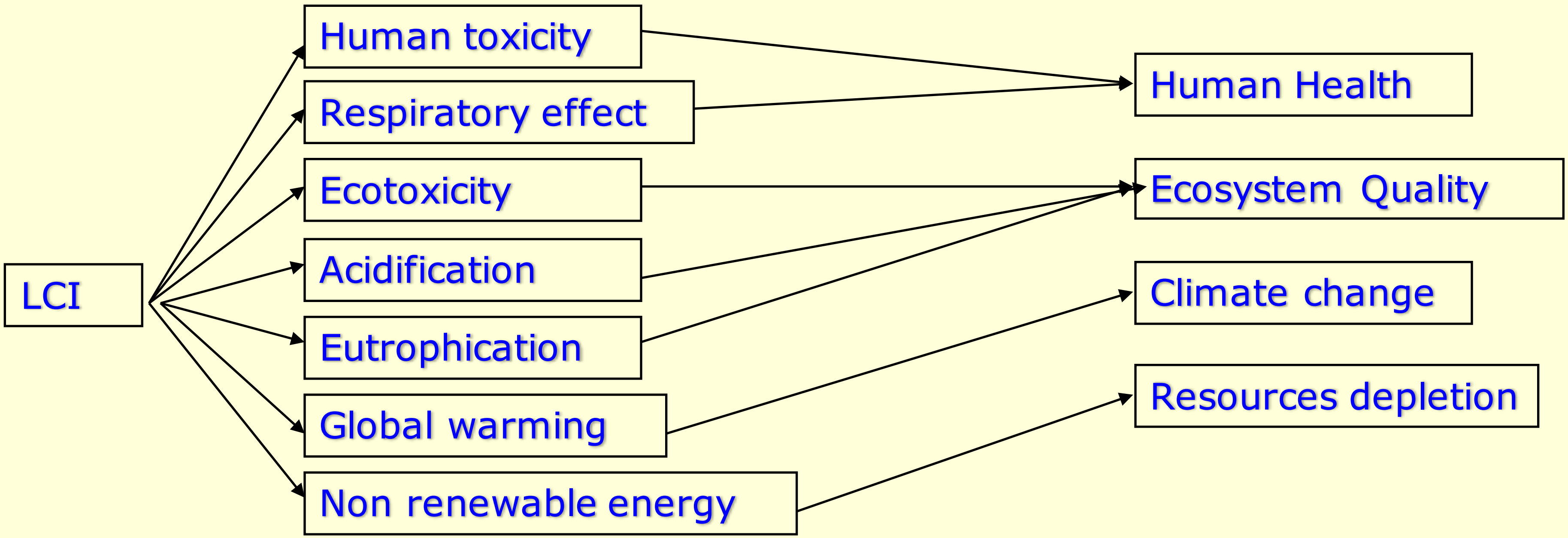
The new process is compared to conventional production lines



Four distinct phases



- Life Cycle Inventory (ISO 14041)



According to Jolliet et al. (2003)

IMPACT2002+

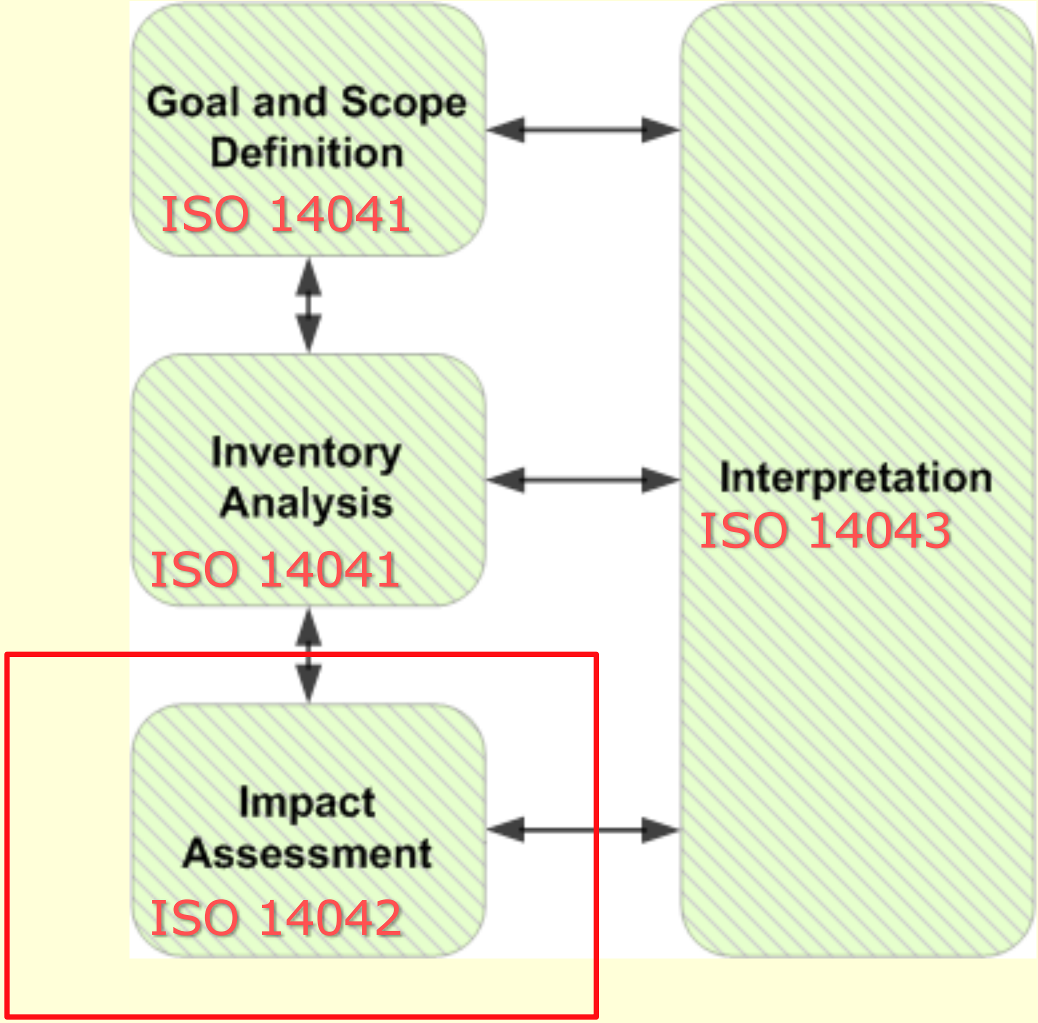
- Life Cycle Inventory (ISO 14041)

An important part of the assessment work

Compartment	Energy demand	Emissions	Feeding material
Fryer	Simulation ##	Experiments #	Sludge/oils
Air dryer	Simulation ##	Experiments **	Sludge/Air/Natural gas
Esterification	Similarity *	Similarity *	Methanol/Catalyst/oils
Combustion	Auto-thermal fuel ##	Simulation/Experiments ##	Air/fry-dried sludge; air
Transportation		Database ***	Diesel
Electricity		Database *	

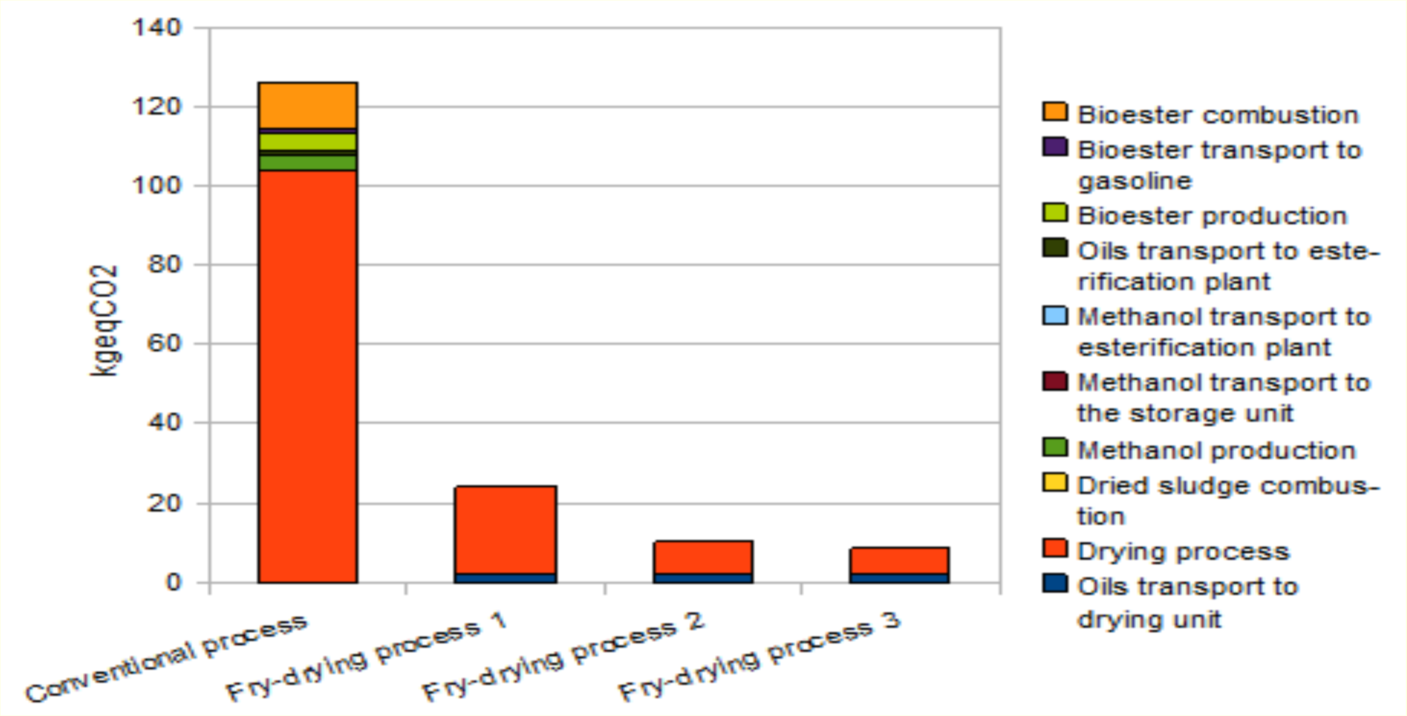
* Ecoinvent, 2007
\# Peregrina, 2006
\## Romdhana, 2009
** Ressent, 1999
*** Spilmann, 2007

Four distinct phases



- Impact assessment and interpretation (ISO 14042-43)

Comparison of climate change impact between processes

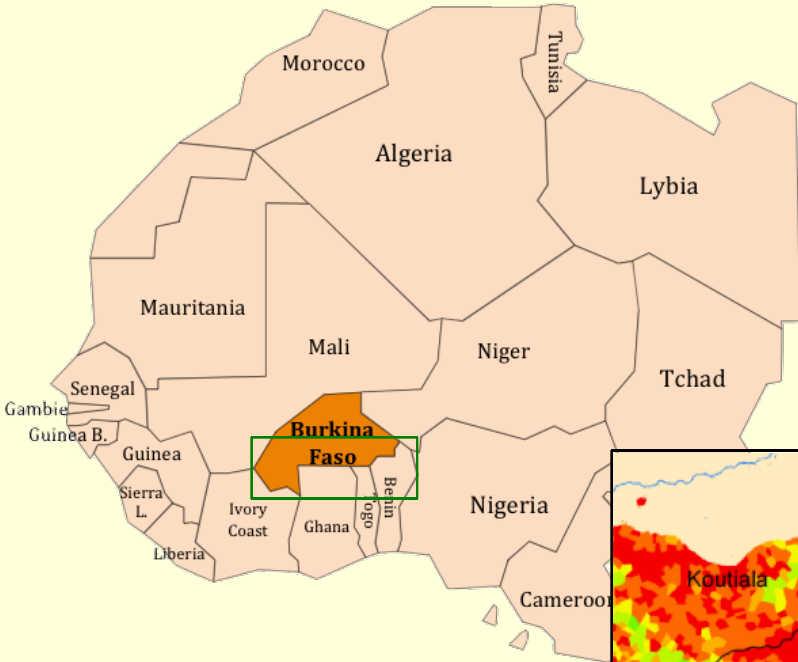


Conventional processes : Air drying process + Estirification + combustion

Fry-drying process 1 : Fry-drying + combustion

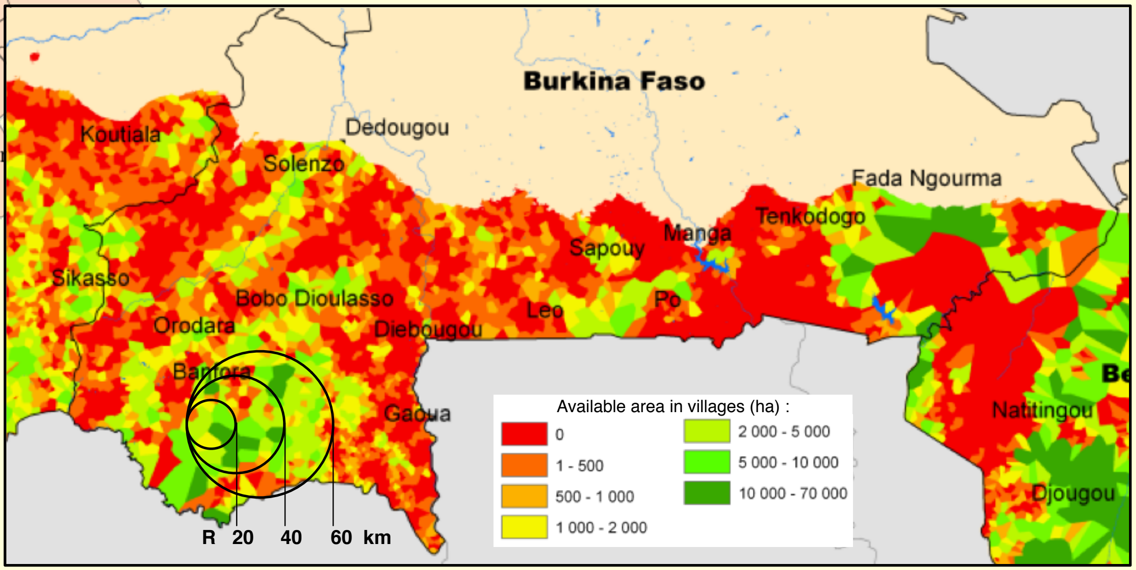
Fry-drying process 2-3 : Fry-drying + combustion + Mechanical compression of vapor

Example 2: Sustainable design of a biofuel production line in Burkina Faso



Burkina Faso, a developing country in a harsh environment

Sahelian climate, rainfall: 500 - 1100 mm
GDP: $ 475 / inhab./year
Access to Electricity: rural area 6%; urban 25%



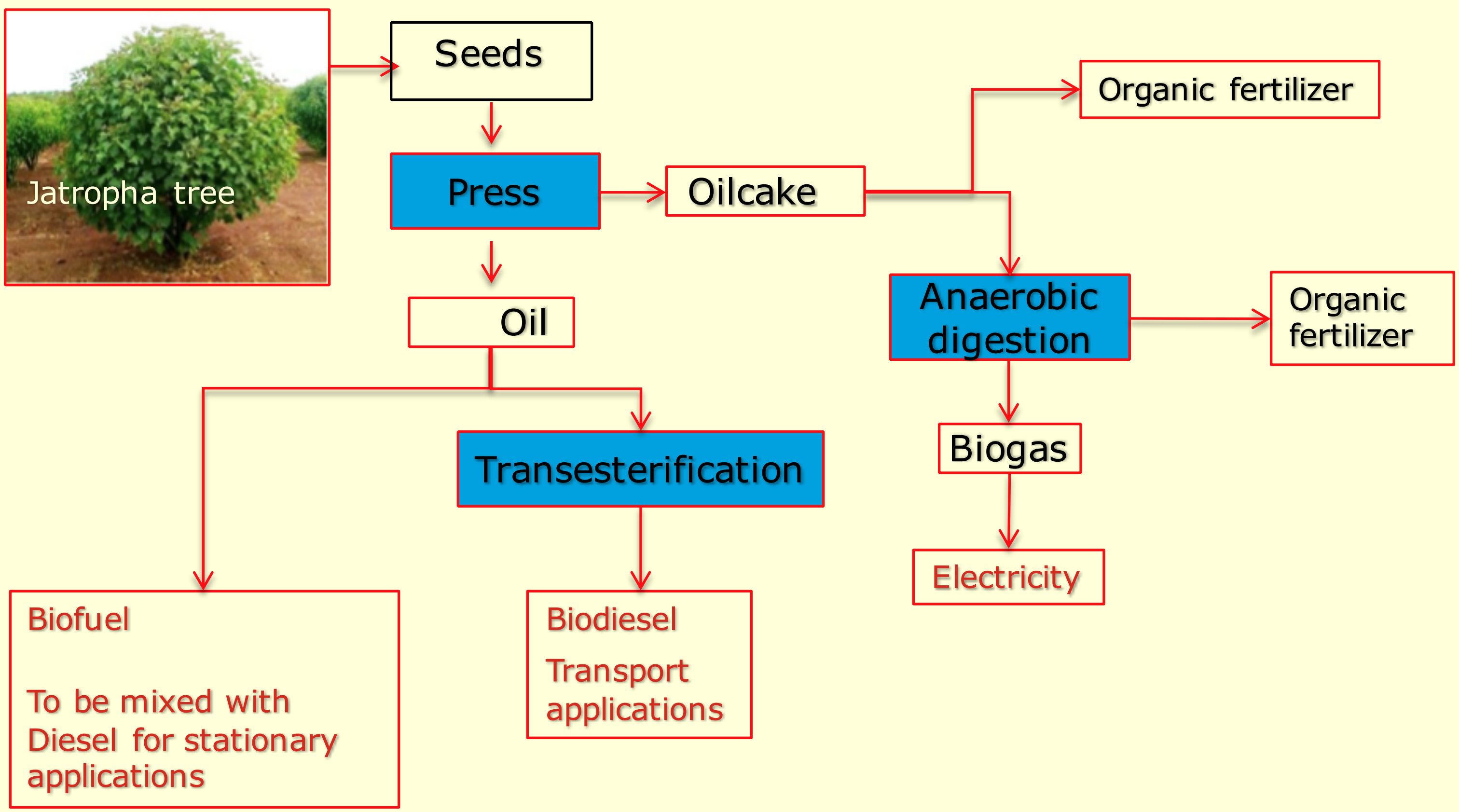
Estimated available areas at village level for Jatropha cultivation in Burkina Faso (adapted from Duba, 2013).

PhD works,
A. Chapuis,
2iE Ouagadougou, CIRAD
and Mines d'Albi

Sustainability assessment of bioenergy production lines

Process description of the production line

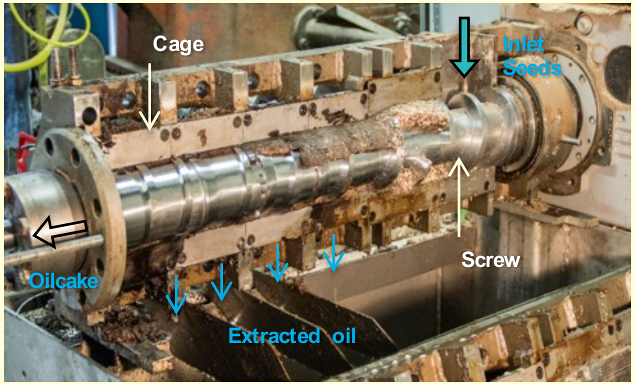
- transport should be taken into account

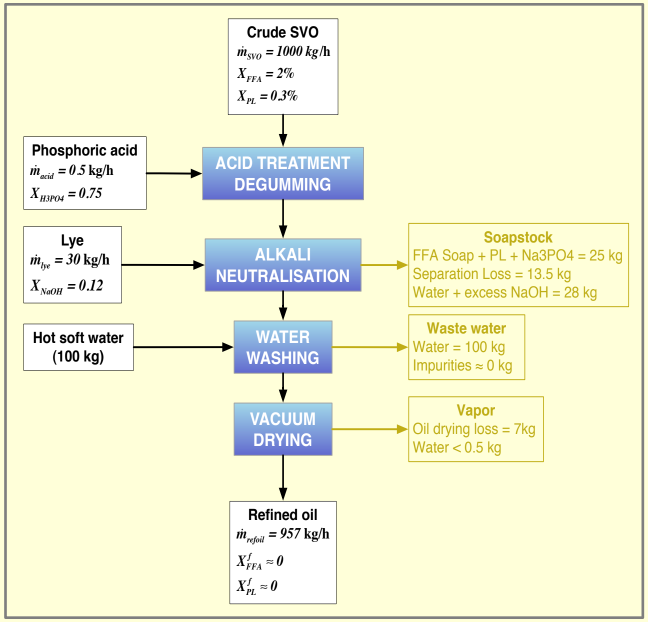


Technical models

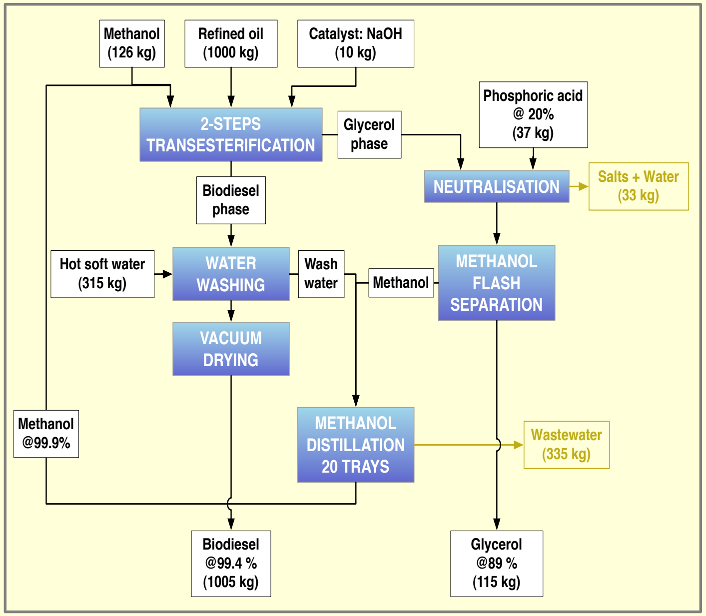
Environmental assessment (ISO 14040)

Economic assessment



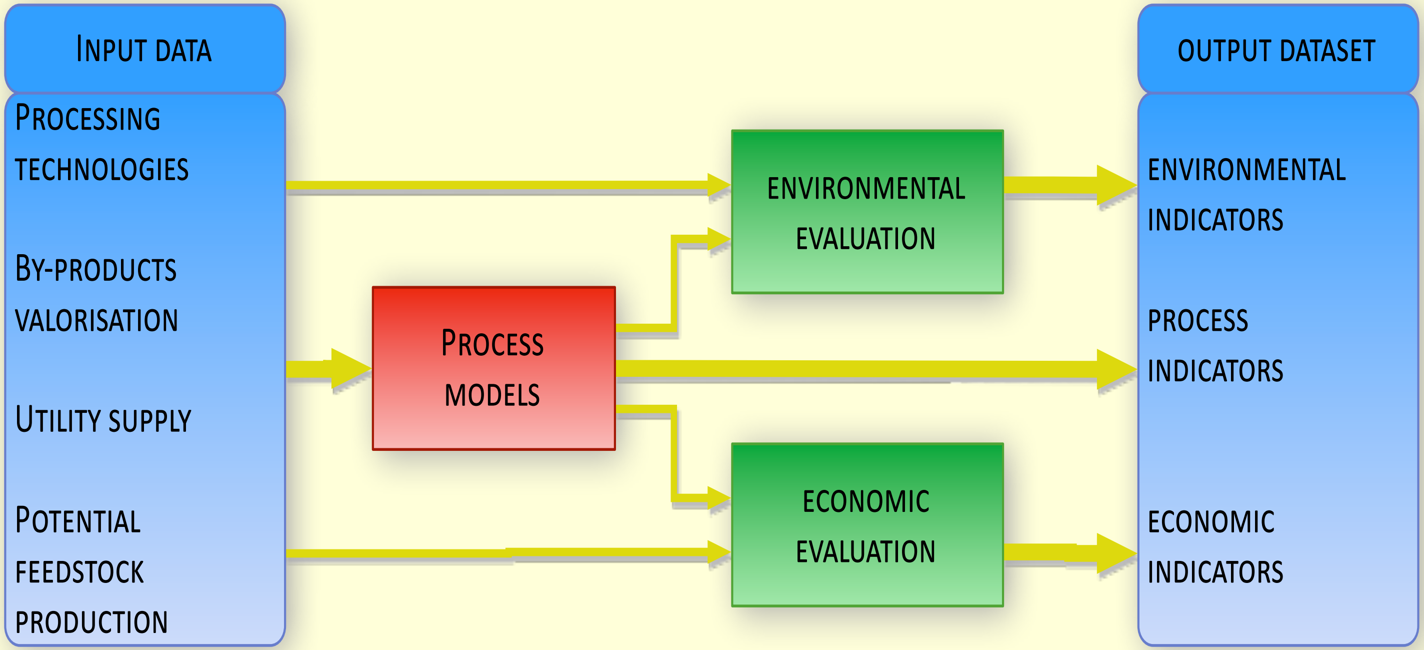


Oil refining



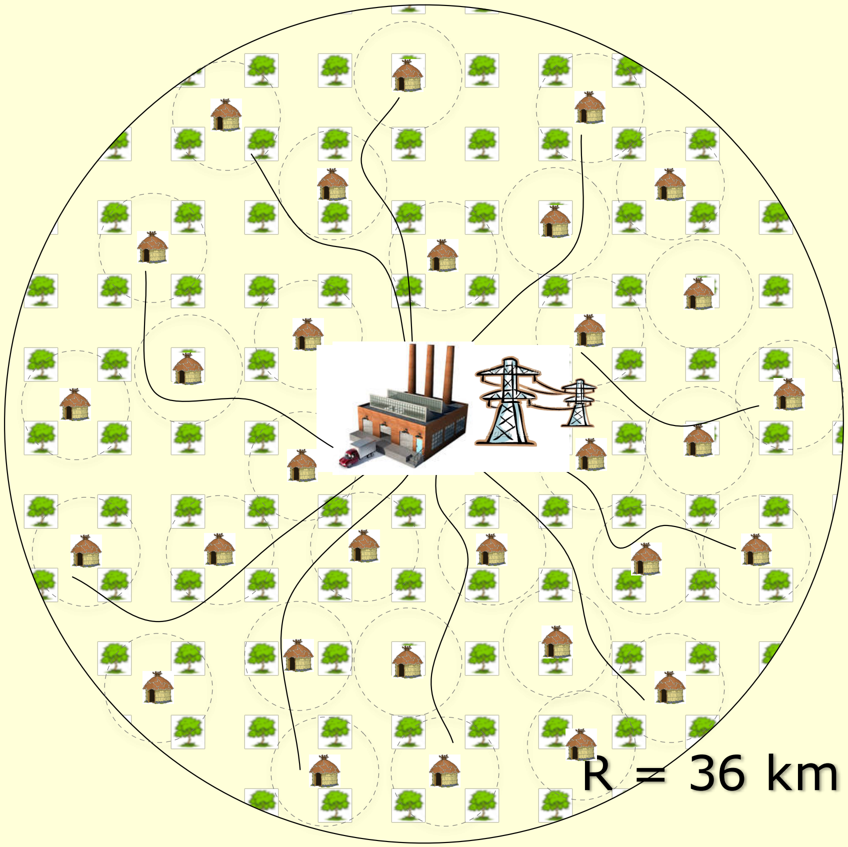
Biodiesel plant

Technical models
Environmental assessment (ISO 14040)
Economic assessment



-> 3 scenarios were assessed

Scenario 1



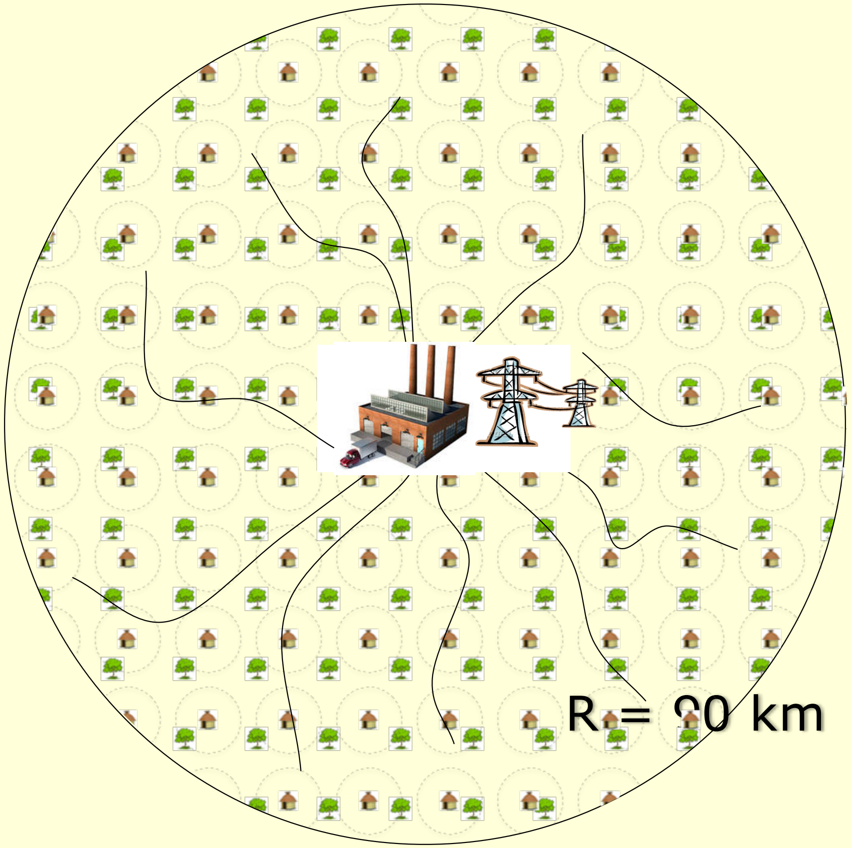
Centralized production, medium-capacity, batch

20,000 ha of jatropha
20 000 t of seeds/year

1 Biodiesel plant
batch process
5000 h / year
Biomass boiler
Electricity Network
4700 t biodiesel produced/year

Biodiesel price = 595 FCFA / L

Scenario 2



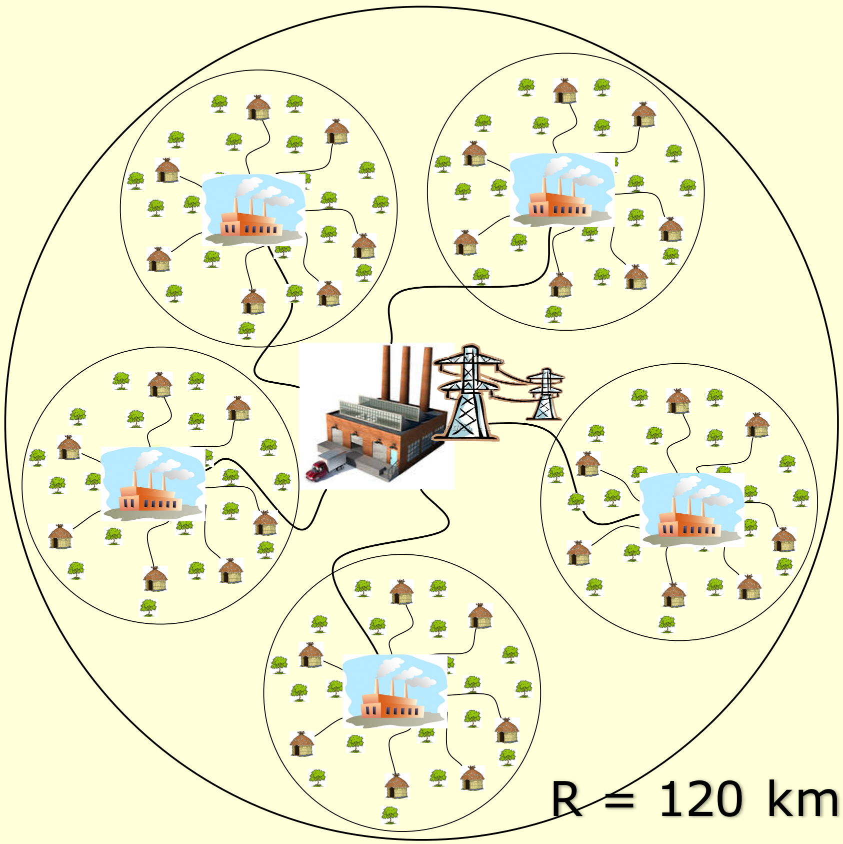
Centralized production, high capacity, continuous

40,000 ha of jatropha
40 000 t of seeds/year

1 Biodiesel plant
Continuous process
7000 h / year
Biomass boiler
Electricity Network
9600 t biodiesel produced/year

Biodiesel price = 595 FCFA / L

Scenario 3



Decentralized production, continuous

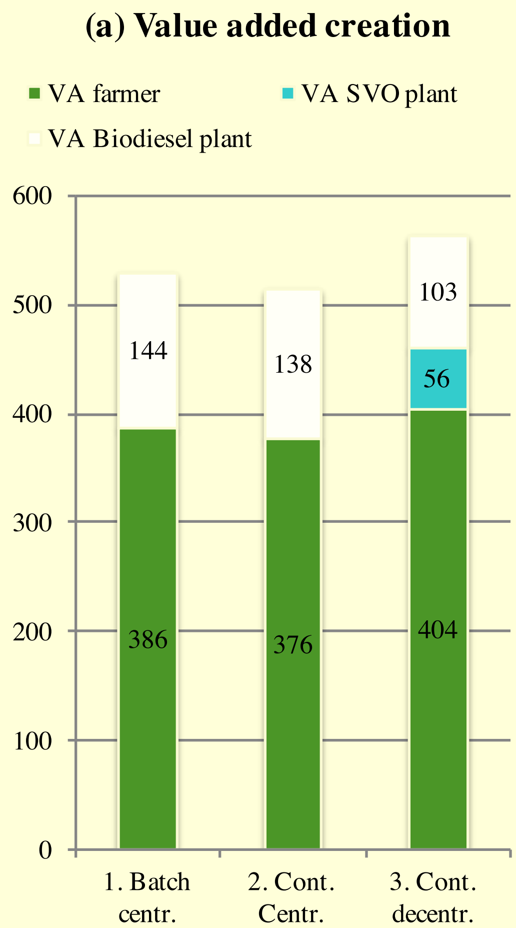
90,000 ha of jatropha
90 000 t of seeds/year

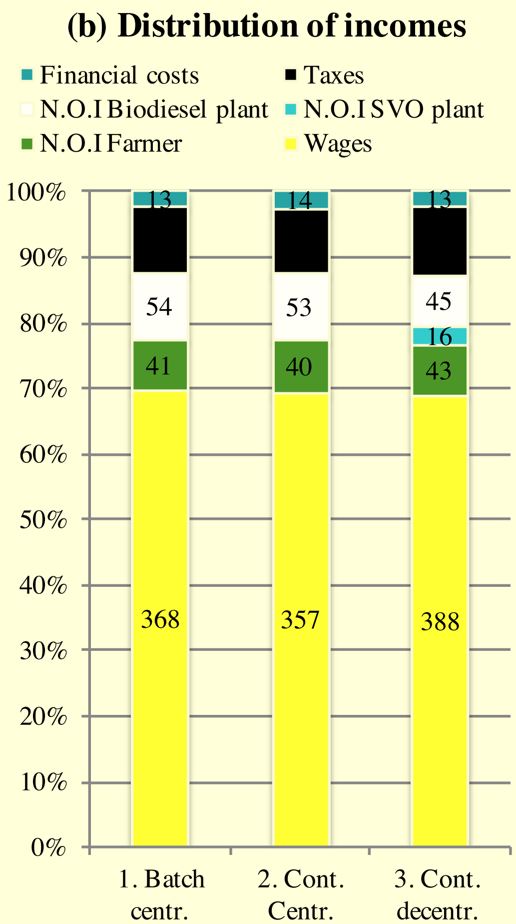
10 Oil mills
9000 t seeds/year (10%)
2000 tons of straight vegetable oil (SVO)
SVO price = 410 FCFA / L

1 Biodiesel plant
Continuous process
7000 h / year
Biomass boiler
Electricity Network
20000 t biodiesel produced/year

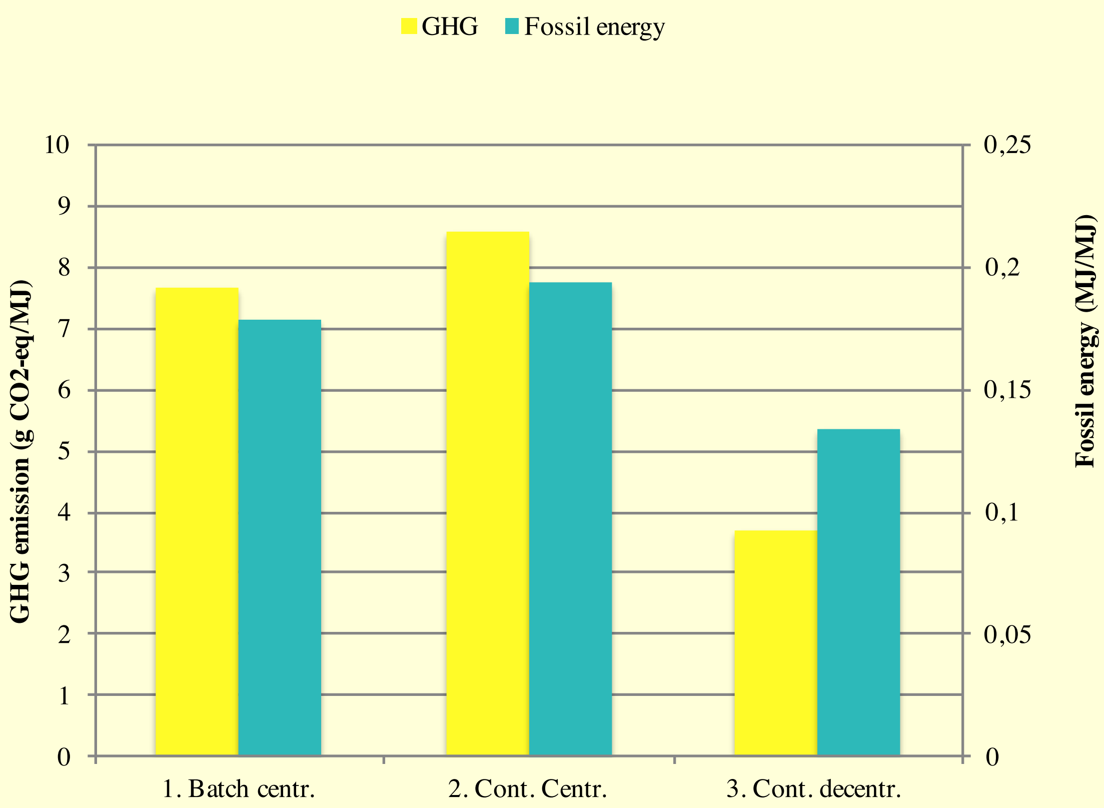
Biodiesel price = 595 FCFA / L

Economical results





Environmental assessment



Conclusion

How to design sustainable bioenergy production lines

- Develop scenarios and test them
- Use realistic information systems or models : biomass yields for crops, equipment efficiency, lifecycle assessment databases
- Update your information with real life data
- Design you own experiments when data are not available
- Check your mass and energy balances
- Be very careful with scaling-up production lines
- Work in a team – a research team
- Do not have prejudice and be humble with your simulation results
- Share your information – with decision makers

Thanks for your attention

Publications

D. Lecomte, A. Nzihou, Editorial: Special Issue - 1st International Conference on Engineering for Waste Treatment : Beneficial Use of Waste and by-Products,, *Process Safety and Environmental Protection.*, Trans. IChemE part. B, 84(B4), pp 235-236, 2006.

C. Peregrina, V. Rudolph, D. Lecomte, P. Arlabosse, Immersion frying for the thermal drying of sewage sludge: an economic assessment, *Journal of Environmental Management*, Vol. 86, pp 246–261, 2008.

M.H. Romdhana, A. Hamasaiid, B. Ladevie, D. Lecomte, Energy valorization of industrial biomass: using a batch frying process for sewage sludge , *Bioresource Technology*, 100, pp. 3740–3744, 2009.

Romdhana, M.H., D. Lecomte, B. Ladevie, C. Sablayrolles., Monitoring of pathogenic microorganisms contamination during heat drying process of sewage sludge, *Process Safety and Environmental Protection* Vol. 87, 6, pp. 377-386, 2009.

D. Lecomte, P. Arlabosse, Valorisation énergétique de la biomasse et des déchets humides, *Sud Sciences et Technologies*, 17, pp. 22-28, 2009.

Chapuis, J. Blin, P. Carré, D. Lecomte, Separation efficiency and energy consumption of oil expression using a screw-press: The case of Jatropha curcas L. seeds, *Industrial Crops and Products*, 52 pp. 752–761, 2014

PhD dissertations

Carlos Peregrina, Traitement des boues par friture : des mécanismes physiques à l'éco-conception d'un procédé, 2005

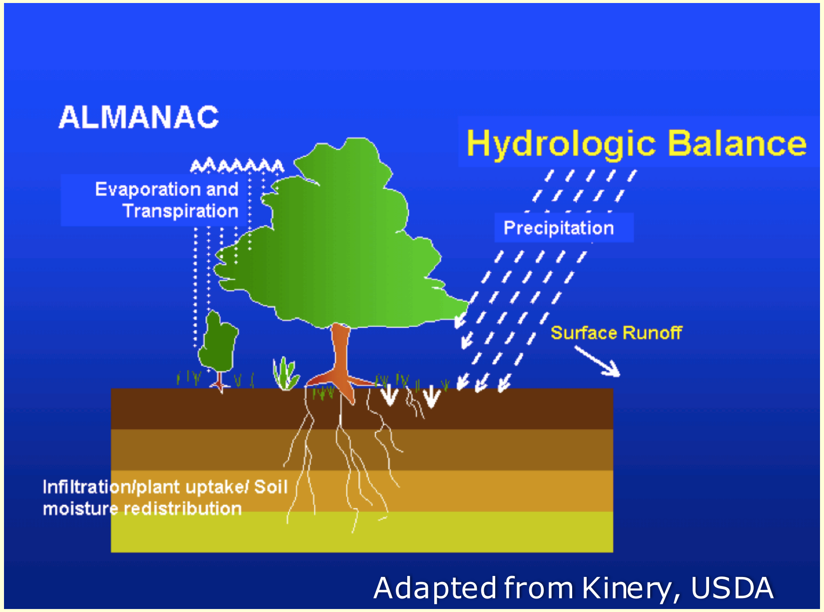
Mohamed Hedi Romdhana, Etude théorique et expérimentale d'un procédé de valorisation de biomasse humide en combustible solide avec récupération d'énergie, 2009 (Prix de these INPT)

Arnaud Chapuis, Sustainable design of oilseed-based biofuel supply chains – the case of Jatropha in Burkina Faso, 2014

Sustainability assessment of bioenergy production lines

Example: biomass yields estimations

ALMANAC model for prediction of biomass yields



http://www.ars.usda.gov/main/docs.htm?docid=16601

Simulation of plant growth:

- Inputs: plant type, soil types, latitudes, and rainfall zones
- Simulation of nutrient and water demands