Life cycle assessments of selected future energy crops for Europe

Nils Rettenmaier

4th Workshop of the 4F CROPS project
Lisbon, 19 November 2010
Who we are - What we do

IFEU - Institute for Energy and Environmental Research Heidelberg, since 1978

• Independent scientific research institute
• organised as a private non profit company with currently about 40 employees
• Research / consulting on environmental aspects of
  - Energy (including Renewable Energy)
  - Transport
  - Waste Management
  - Life Cycle Analyses
  - Environmental Impact Assessment
  - Renewable Resources
  - Environmental Education
Who we are - What we do

IFEU focuses regarding the topic of biomass

- Research / consulting on environmental aspects of
  - transport biofuels
  - biomass-based electricity and heat
  - biorefinery systems
  - biobased materials
  - agricultural goods and food
  - cultivation systems (conventional agriculture, organic farming, etc.)

- Potentials and future scenarios
- Technologies / technology comparisons
- CO₂ avoidance costs
- Sustainability aspects / valuation models
Who we are - What we do

TREMOMD: Transport Emission Model

- Modelling emissions of road vehicles, trains, ships and airplanes
- Official database of the German Ministries for emission reporting

Life cycle analyses (LCA) and technology impact assessments since 1990:

- Biofuels (all biofuels, all applications)
- Alternative transportation modes
- Renewable Energy
Who we are - What we do

IFEU - Institute for Energy and Environmental Research Heidelberg, since 1978

Our clients (on biomass studies)

- World Bank
- UNEP, FAO, UNFCCC, GTZ, etc.
- European Commission
- National and regional Ministries
- Associations (industrial, scientific)
- Local authorities
- WWF, Greenpeace, Friends of the Earth etc.
- Companies (Daimler, German Telecom, Shell etc.)
- Foundations (German Foundation on Environment, etc.)
Life cycle assessments of selected future energy crops for Europe

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Life cycle analyses for 4F CROPS

Life cycle assessment of selected future energy crops for Europe

Article based on results of the 4F CROPS project.

Authors:
Nils Rettenmaier, Susanne Köppen, Sven Gärtner & Guido Reinhardt

Project duration:
Jun 2008 – Nov 2010
4F CROPS: Environmental analysis

WP8: Coordination Management and Reporting

WP1. Land Use in EU27
WP2. Cropping Possibilities
WP3. Economic Analysis and Social impacts
WP4. Environmental Analysis
WP5. Regulatory Framework


WP7: Dissemination and Supports Actions
Outline

• **Introduction: Life cycle assessment (LCA)**

• **LCA of future energy crops for Europe**
  • Selection of crops and bioenergy chains
  • General settings

• **Main results**
  • Bioenergy versus fossil energy
  • Comparison of bioenergy chains
  • Sensitivity analyses

• **Conclusions**
Biofuels and bioenergy

Environmental advantages and disadvantages:

+ CO₂ neutral
+ Save energetic resources
+ Organic waste reduction
+ Less transport
+ etc.

- Land use
- Eutrophication of surface water
- Water pollution by pesticides
- Energy intensive production
- etc.

Total:
positive or negative

?
"Hey, I thought we were working with the same data..."
Life cycle analysis (LCA)

ISO 14040 & 14044

Goal and scope definition

Inventory analysis

Impact assessment

Interpretation
Life cycle analysis (LCA)

ISO 14040 & 14044

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation

ISO 14040 & 14044

Life cycle analysis (LCA)
LCA: Inventory Analysis

**Inputs**

- natural gas
- crude oil
- brown coal
- hard coal
- uranium
- water

**Outputs**

- CO₂
- SO₂
- CH₄
- NOₓ
- NH₃
- N₂O
- HCl
- CO
- C₆H₆
- VOC
Life cycle analysis (LCA)

ISO 14040 & 14044

Goal and scope definition → Inventory analysis → Impact assessment → Interpretation

Goal and scope definition

Inventory analysis

Impact assessment

Interpretation
<table>
<thead>
<tr>
<th>Impact category</th>
<th>Parameter</th>
<th>Substances (LCI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource demand</td>
<td>Sum of depletable primary energy carriers</td>
<td>Crude oil, natural gas, coal, Uranium, …</td>
</tr>
<tr>
<td></td>
<td>Mineral resources</td>
<td>Lime, clay, metal ores, salt, pyrite, …</td>
</tr>
<tr>
<td>Greenhouse effect</td>
<td>CO$_2$ equivalents</td>
<td>Carbon dioxide, dinitrogen monoxide, methane, different CFCs, methyl bromide, …</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>CFC-11 equivalents</td>
<td>Dinitrogen monoxide, CFC, halone, methyl bromide, …</td>
</tr>
<tr>
<td>Acidification</td>
<td>SO$_2$ equivalents</td>
<td>Sulphur dioxide, hydrogen chloride, nitrogen oxides, ammonia, …</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>PO$_4$ equivalents</td>
<td>Nitrogen oxides, ammonia, phosphate, nitrate</td>
</tr>
<tr>
<td>Photosmog</td>
<td>C$_2$H$_4$ equivalents</td>
<td>Hydrocarbons, nitrogen oxides, carbon monoxide, chlorinated hydrocarbons, …</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>PM10 equivalents</td>
<td>Nitrogen oxides, carbon monoxide, hydrogen chloride, diesel particles, dust, ammonia, benzene, benzo(a)pyrene, sulphur dioxide, dioxines (TCDD), …</td>
</tr>
</tbody>
</table>
# Normalisation

**Inhabitant equivalents: average footprint of EU27 citizen**

<table>
<thead>
<tr>
<th>Environmental impact category</th>
<th>Unit</th>
<th>EU27 inhabitant equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary energy use</td>
<td>GJ / yr</td>
<td>82</td>
</tr>
<tr>
<td>Greenhouse effect</td>
<td>t CO₂ equivalent / yr</td>
<td>11</td>
</tr>
<tr>
<td>Acidification</td>
<td>kg SO₂ equivalent / yr</td>
<td>49</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg PO₄ equivalent / yr</td>
<td>6</td>
</tr>
<tr>
<td>Summer smog (POCP)</td>
<td>kg C₂H₄ equivalent / yr</td>
<td>20</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>kg CFC-11 equivalent / yr</td>
<td>0.069</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg PM10 equivalent / yr</td>
<td>40</td>
</tr>
</tbody>
</table>
Outline

• Introduction: Life cycle assessment (LCA)
• LCA of future energy crops for Europe
  • Selection of crops and bioenergy chains
  • General settings
• Main results
  • Bioenergy versus fossil energy
  • Comparison of bioenergy chains
  • Sensitivity analyses
• Conclusions
## Selection of crops

<table>
<thead>
<tr>
<th>MAIN PRODUCT</th>
<th>CLIMATIC AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nemoral</td>
</tr>
<tr>
<td>Oil</td>
<td></td>
</tr>
<tr>
<td>Rapeseed</td>
<td></td>
</tr>
<tr>
<td>Lignocellulosic: Wood</td>
<td></td>
</tr>
<tr>
<td>Poplar</td>
<td></td>
</tr>
<tr>
<td>Lignocellulosic: Herbaceous</td>
<td></td>
</tr>
<tr>
<td>Reed canary grass</td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
</tr>
</tbody>
</table>

Source: UNICT 2009
### Data collection

#### Projected average yields of marketable product for 2020

<table>
<thead>
<tr>
<th>[t fresh matter / ha]</th>
<th>ATC</th>
<th>ATN</th>
<th>CON</th>
<th>MDS</th>
<th>MDN</th>
<th>NEM</th>
<th>LUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethiopian mustard</td>
<td>2.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapeseed</td>
<td>3.5</td>
<td>2.5</td>
<td>3.1</td>
<td></td>
<td>2.1</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Sunflower</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eucalyptus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>Poplar</td>
<td>7.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12.1</td>
<td>9.6</td>
</tr>
<tr>
<td>Willow</td>
<td></td>
<td>8.3</td>
<td>8.8</td>
<td></td>
<td></td>
<td></td>
<td>6.8</td>
</tr>
<tr>
<td>Cardoon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20.3</td>
<td></td>
</tr>
<tr>
<td>Giant reed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51.3</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>31.8</td>
<td>15.9</td>
<td>32.3</td>
<td></td>
<td></td>
<td></td>
<td>33.8</td>
</tr>
<tr>
<td>Reed canary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14.7</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>18.4</td>
<td>12.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet</td>
<td>88.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet Sorghum</td>
<td></td>
<td>8.4</td>
<td>6.4</td>
<td></td>
<td></td>
<td></td>
<td>5.8</td>
</tr>
</tbody>
</table>

Source: UNICT 2009
IFEU has selected **representative conversion paths and products** taking into account relevant literature.

<table>
<thead>
<tr>
<th>Crop category</th>
<th>Conversion path</th>
<th>Main product</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil crops</td>
<td>Combustion</td>
<td>Heat &amp; power</td>
<td>Light fuel oil &amp; UCTE mix</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat</td>
<td>Light fuel oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power</td>
<td>UCTE mix</td>
</tr>
<tr>
<td></td>
<td>Transesterification</td>
<td>Biodiesel (FAME)</td>
<td>Diesel fuel</td>
</tr>
<tr>
<td></td>
<td>Hydrotreatment</td>
<td>Biofuel (HVO)</td>
<td>Diesel fuel</td>
</tr>
<tr>
<td>Lignocellulosic crops (woody &amp; herbaceous)</td>
<td>Combustion</td>
<td>Heat &amp; power</td>
<td>Light fuel oil &amp; UCTE mix</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat</td>
<td>Light fuel oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power</td>
<td>UCTE mix</td>
</tr>
<tr>
<td></td>
<td>Hydrolysis &amp; fermentation</td>
<td>Second generation EtOH</td>
<td>Gasoline</td>
</tr>
<tr>
<td></td>
<td>Gasification &amp; FT synthesis</td>
<td>FT-diesel</td>
<td>Diesel fuel</td>
</tr>
<tr>
<td>Sugar crops</td>
<td>Fermentation</td>
<td>First generation EtOH</td>
<td>Gasoline</td>
</tr>
</tbody>
</table>

Source: Rettenmaier et al. 2010
Outline

- **Introduction: Life cycle assessment (LCA)**
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Detailed results: Sugar beet EtOH

- Credits
- Expenditures

- Energy savings
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog (POCP)
- Ozone depletion
- Human toxicity

- Advantages
- Disadvantages

- Energy savings
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog (POCP)
- Ozone depletion
- Human toxicity

Source: Rettenmaier et al. 2010
## Overall environmental performance

<table>
<thead>
<tr>
<th>Biofuel</th>
<th>Energy savings</th>
<th>Greenhouse effect</th>
<th>Acidification</th>
<th>Eutrophication</th>
<th>Summer smog</th>
<th>Ozone depletion</th>
<th>Human toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil crops – FAME</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Oil crops – HVO</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Oil crops – Heat &amp; power</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Oil crops – Heat</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Oil crops – Power</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Woody crops – FT diesel</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Woody crops – 2nd gen. EtOH</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Woody crops – Heat &amp; power</td>
<td>+ +</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Woody crops – Heat</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Woody crops – Power</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Herb. crops – FT diesel</td>
<td>+ +</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Herb. crops – 2nd gen. EtOH</td>
<td>+ +</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Herb. crops – Heat &amp; power</td>
<td>+ + +</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Herb. crops – Heat</td>
<td>+ +</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Herb. crops – Power</td>
<td>+ +</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Sugar crops – 1st gen. EtOH</td>
<td>+ +</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>--</td>
<td>0</td>
</tr>
</tbody>
</table>

IE values per 100 hectares:

“++ +” : < -400; “++” : -400 to – 100; “+” : - 100 to -25; “o” : -25 to 25; “-” : 25 to 100; “- -” : 100 to 400;

Source: Rettenmaier et al. 2010
1. All assessed biofuels and bioenergy carriers show **environmental advantages as well as disadvantages** when compared to their fossil / conventional equivalents.

2. Most biofuels and bioenergy carriers show **advantages** with regard to energy savings and greenhouse effect.

3. In contrast, most biofuels and bioenergy carriers show **disadvantages** with regard to acidification, eutrophication, ozone depletion and human toxicity.

4. The results don‘t show clear tendencies with regard to summer smog.
Life cycle analysis (LCA)

ISO 14040 & 14044

Goal and scope definition

Inventory analysis

Impact assessment

Interpretation
Statistics about Heidelberg

<table>
<thead>
<tr>
<th>Category</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhabitants</td>
<td>130,000</td>
</tr>
<tr>
<td>School buildings (including university)</td>
<td>180</td>
</tr>
<tr>
<td>Bridges</td>
<td>5</td>
</tr>
<tr>
<td>Dogs</td>
<td>220</td>
</tr>
<tr>
<td>Tourists per day</td>
<td>5,500</td>
</tr>
<tr>
<td>Total</td>
<td>135,905</td>
</tr>
</tbody>
</table>
### LCA: Interpretation

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Parameter</th>
<th>Ecological significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource demand</td>
<td>Cumulative energy demand (non-renew.)</td>
<td>important</td>
</tr>
<tr>
<td>Greenhouse effect</td>
<td>CO$_2$ equivalents</td>
<td>very important</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>CFC-11 equivalents</td>
<td>(very) important</td>
</tr>
<tr>
<td>Acidification</td>
<td>SO$_2$ equivalents</td>
<td>medium relevance</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>PO$_4$ equivalents</td>
<td>medium relevance</td>
</tr>
<tr>
<td>Human- and Ecotoxicity</td>
<td>Nitrogen oxide</td>
<td>medium relevance</td>
</tr>
<tr>
<td>Human- and Ecotoxicity</td>
<td>Diesel particulates</td>
<td>very important</td>
</tr>
</tbody>
</table>
5. An **objective decision** for or against a particular biofuel or bioenergy carrier **cannot be made**. However, based on subjective value-choices, a decision is possible.

6. If, for example, energy savings and greenhouse effect is given the highest priority, all biofuels and bioenergy carriers assessed are to be preferred over their fossil equivalents.

7. The amount of energy and greenhouse gases that can be saved greatly differs depending on the crops, conversion paths and main products, i.e. the entire life cycle has to be taken into account.
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- Conclusions
Comparison of environment zones

Atlantic Central
- Oil crop
- Woody crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop

Atlantic North
- Oil crop
- Woody crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop

Continental
- Oil crop
- Woody crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop

Lusitanian
- Oil crop
- Woody crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop

Mediterranean North
- Oil crop
- Woody crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop

Mediterranean South
- Oil crop
- Woody crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop

Nemoral
- Oil crop
- Woody crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop

Source: Rettenmaier et al. 2010

Energy savings
Greenhouse effect

-700 -600 -500 -400 -300 -200 -100 0 IE / 100 ha

Oil crop
- Herb. crop 1
- Herb. crop 2
- Sugar crop
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• Conclusions
Sensitivity analyses

Variations & sensitivity analyses done:

- Variation of agricultural reference system
- Variation of yields
  - Differences between environmental zones
  - Yield increase over time (2008 vs. 2020 vs. 2030)
- Variation of co-product use
- Variation of co-product allocation
- Variation of stationary energy use
- Variation of substituted power mix
Agricultural ref. system and LUC

Agricultural reference system incl. land-use change (LUC)

dLUC

iLUC

Crude oil extraction

Biomass cultivation

Energy crop

Transport

Refining

Conversion

Feed

Bioenergy carrier

Use

Energy crop

Transport

Conversion

Feed

Bioenergy carrier

Use

Fallow

Europe

Wheat

Europe

Grassland on organic soil

Europe

Soy

Europe

Soy

Europe

Grassland

Brazil

Prairie

USA

Tropical rainforest

Brazil

Grassland

Brazil

Source: Rettenmaier et al. 2010

Ia – IIIb: Scenarios

Product

Process

Reference system
# LUC: Carbon stock changes

<table>
<thead>
<tr>
<th>Name</th>
<th>N°</th>
<th>Carbon stock changes &amp; GHG emissions due to crop cultivation (Miscanthus &amp; sugar beet)</th>
<th>Carbon stock changes due to co-products (only sugar beet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow dLUC</td>
<td>I a</td>
<td>Replacing fallow: ±0 t C / ha</td>
<td>Land release not considered</td>
</tr>
<tr>
<td>Fallow iLUC</td>
<td>I b</td>
<td>Replacing fallow: ±0 t C / ha</td>
<td>Land release in Brazil: +10 t C / ha&lt;sup&gt;30&lt;/sup&gt;</td>
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<td>Cereals dLUC</td>
<td>II a</td>
<td>Replacing cereals in Europe: ±0 t C / ha</td>
<td>Land release not considered</td>
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<td>Cereals iLUC</td>
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<tr>
<td>Grassland dLUC</td>
<td>III a</td>
<td>Replacing grassland on organic soil in Europe: −13 t C / ha&lt;sup&gt;30&lt;/sup&gt;</td>
<td>Land release not considered</td>
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<td></td>
<td></td>
<td>Continuous GHG emissions from organic soil: 6 t C / (ha*yr)&lt;sup&gt;31&lt;/sup&gt;</td>
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<tr>
<td>Grassland iLUC</td>
<td>III b</td>
<td>Replacing grassland on organic soil in Europe: −13 t C / ha&lt;sup&gt;30&lt;/sup&gt;</td>
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<td>Continuous GHG emissions from organic soil: 6 t C / (ha*yr)&lt;sup&gt;31&lt;/sup&gt;</td>
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<td></td>
<td>Displacing feed production to Brazilian forests: -160 t C / ha&lt;sup&gt;30&lt;/sup&gt;</td>
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Source: Rettenmaier et al. 2010
<table>
<thead>
<tr>
<th>Country</th>
<th>Fuel oil &amp; natural gas</th>
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<th>Uranium</th>
<th>Hydro</th>
<th>Other renewable</th>
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<td>4%</td>
<td>7%</td>
<td>84%</td>
<td>5%</td>
<td>1%</td>
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<tr>
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<td>28%</td>
<td>2%</td>
<td>3%</td>
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<tr>
<td>Poland</td>
<td>4%</td>
<td>93%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
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</tbody>
</table>
Variation of substituted power mix

Advantages

Disadvantages

Willow Power

Energy savings

Greenhouse effect

Acidification

Eutrophication

Source: Rettenmaier et al. 2010
Outline

- Introduction: Life cycle assessment (LCA)
- LCA of future energy crops for Europe
  - Selection of crops and bioenergy chains
  - General settings
- Main results
  - Bioenergy versus fossil energy
  - Comparison of bioenergy chains
  - Sensitivity analyses
- Conclusions
Environmental advantages and disadvantages

- Environmental advantages in terms of energy and GHG savings for all crops, environmental zones, and bioenergy chains
- But: Ambiguous results or even disadvantages other impact categories
- No scientifically objective conclusion regarding overall environmental performance can be drawn.
- The conclusion has to be drawn on subjective value-choices.
Best energy crops and bioenergy chains

• Herbaceous lignocellulosic crops are the most land-use-efficient options in terms of energy and GHG savings

• Stationary use of biomass (heat and/or power) usually outperforms the mobile use as transport biofuel
  • But: Quantitative results depend on case-specific conditions, in particular the replaced power mix.

• Bioethanol shows better results than all diesel substitutes

• Regarding first and second generation EtOH, no clear tendency could be found
Effects of methodological data choices

- Most important single factor influencing the LCA is choice of agricultural reference systems including LUC.
- In case of bioenergy production on non-surplus land (replacement of food and feed production) even higher GHG emissions than by using fossil energy carriers possible.
  - But: research on iLUC still in its infancy.
Conclusions

1. As land-use competitions are increasing, it is necessary to allocate the limited amount of biomass to the different sectors (food / feed / fiber and fuel) in such a way which achieves the highest environmental benefits.

2. LCAs are a suitable tool for environmental assessments. By means of sensitivity and weakness analyses, optimisation potentials can be identified.

3. The use of biomass can be significantly optimized from an environmental point of view by taking into account different biomass and co-product uses or site-specific conditions, e.g. power mixes in different countries.
Conclusions

4. Hence, LCA is a suitable scientific tool for policy analysis and decision making.

5. However, if local or regional concerns come into play, an Environmental Impact Assessment (EIA) will be necessary.
Thank you for your attention!

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