ECONOMICS of POPULAR PYROLYSIS
stemming from PHYTOREMEDIATION
of METAL POLLUTED SOILS
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Research group Environmental Economics

Overview
- Problem statement: profitability of bio-oil production
- Methodology: cost-benefit analysis & risk analysis
- Pyrolysis: oil yields & combined heat & power (CHP) production
- Economic model: investment; expenditures & revenues
- Base case: results & sensitivity analysis
- Optimistic and pessimistic scenario analysis
- Discussion and conclusions

Campine region: cadmium pollution
Cd concentrations exceed threshold values for agriculture
Vast area of 3400 ha of farmland in the Belgian Campine require soil remediation
Phytoremediation is better suited (costs) than conventional soil remediation

Phytoremediation
- Phytoextraction
  - Special form of phytoremediation
  - Metal uptake by plant
  - Translocation of metals from soil to harvestable parts of the plant

= biomass
Problem: output price (farmer) versus input price (oil producer)

The poplar price ($p_{\text{poplar}}$) is the maximal price an investor in a pyrolysis installation is willing to pay for the use of poplar as a feedstock for the conversion plant.

Guaranteeing a 95% chance of a positive net present value of cash flows generated by the investment, the poplar price thus should be determined by taking into account uncertainties/risks of the project.

Risk analysis (1)

Risk analysis (2)

How to measure economic risk?
- Monte Carlo simulations (MC)
  - How sensitive is the NPV of the cash flows for changes in the values of the input variables (e.g., yearly volume of biomass; oil yield (wt%); sales of heat) in the simulation model?
  - Requires knowledge (assumptions) about minimal, most probable and maximal values of input variables and their respective frequency of appearance.
  - Results in probability distribution of NPV after thousands of simulations.

Thermochemical conversion

Pyrolysis
- Lower process temperatures $\rightarrow$ metals are concentrated in char
- Slow pyrolysis $\rightarrow$ max! char formation (but market value of biochar is unknown)
- Flash pyrolysis: quantity of $O_2$ added / $O_2$ required for complete combustion = 0 $\rightarrow$ max! oil formation
Flash pyrolysis

Anaerobic cracking of biomass molecules (lignin, cellulose) into solid and gaseous fraction

13 – 25 wt. % biogas

Internal energy consumption

52 – 71 wt. % pyrolysis oil

Calorific value: 17.5 GJ/ton

16 – 23 wt. % char

Internal energy consumption

Conversion process

Poplar (SRC) → Pyrolysis reactor → Pyrolysis oil → CHP engine → Electricity and heat

10% flue losses
5% radiation losses

100% primary fuel

50% heat
35% electric

Revenues & Expenditures

(net present value over 20 yrs, 1,000 Euro)

Cultivated surface

Growing “willingness to engage in poplar” by farmers

20,000 tons poplar

11,292 tons poplar
Cash flows

- Revenues
- Expenditure

Economies of scale

Year

Revenues (Inv = 5,974)
Expenditure (Inv = 6,409)

1,000 Euro

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Overview

Median NPV (base case) & importance of 5 base case ranges

<table>
<thead>
<tr>
<th>Row</th>
<th>Variable</th>
<th>Minimum</th>
<th>Middle</th>
<th>Maximum</th>
<th>NPV sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Biomass price</td>
<td>31,5 EUR/odt</td>
<td>35 EUR/odt</td>
<td>38,5 EUR/odt</td>
<td>-2.0%</td>
</tr>
<tr>
<td>2</td>
<td>Starting surface $S_{year 1}$</td>
<td>607.5 ha</td>
<td>675 ha</td>
<td>742.5 ha</td>
<td>5.0%</td>
</tr>
<tr>
<td>3</td>
<td>Oil yield $Y_{oil}$</td>
<td>63 wt.%</td>
<td>70 wt.%</td>
<td>77 wt.%</td>
<td>92.5%</td>
</tr>
<tr>
<td>4</td>
<td>Heat sales $Q_{sold}$</td>
<td>45 %</td>
<td>50 %</td>
<td>55 %</td>
<td>0.4%</td>
</tr>
<tr>
<td>5</td>
<td>Discount rate $i$</td>
<td>8.1 %</td>
<td>9 %</td>
<td>9.9 %</td>
<td>0.0%</td>
</tr>
<tr>
<td>6</td>
<td>Median NPV</td>
<td>-696,174</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Probability NPV &gt; 0</td>
<td>Risk (NPV&lt;0) = 14%</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Risk (NPV<0) = 14%
Cultivated surface

![Cultivated Surface Graph]

```
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
```

Maximum price poplar

**Condition:** 95% probability that NPV of the pyrolysis investment > 0

<table>
<thead>
<tr>
<th>Surf. occupied by poplar (ha)</th>
<th>Pessimistic</th>
<th>Base case</th>
<th>Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface occupied by poplar (ha)</td>
<td>300</td>
<td>675</td>
<td>850</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Max price poplar (€/odt)</th>
<th>Optimistic</th>
<th>Base case</th>
<th>Pessimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>max price poplar (€/odt)</td>
<td>-20</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>

Conclusions (1)

1. Installation: 1.6 odt/hr (year 1-10); 2.8 odt/hr (year 11-20)
2. Base case:
   1. Assumptions: 675 ha; 70% oil yield; 50% heat sold
   2. Net present value (NPV) cash flows: 696,000 Euro (mean value)
   3. Probability of a positive NPV of the cash flows: 86%.
   4. Sensitiveness analysis: most important determinants:
      1. oil yield
      2. yearly volume of poplar (cultivated surface)
      3. % of heat sold locally

Conclusions (2)

3. **Maximum poplar price** (€/ton): scenarios (95 % prob >0)
   1. Larger surface: -20; 30; 40 €/ton
   2. Larger oil yield: -5; 30; 60 €/ton
   3. Larger % heat sold: 25; 30; 35 €/ton
4. Explanation
   1. Returns to scale: average oil production cost decrease with larger volume biomass
   2. Cost are based on the supplied volume of processed biomass (odt/year)
   3. Greater valorisation of heat output
Discussion

Questions?

Suggestions?

Thank you for your attention!

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