Adoption dynamics in bioenergy markets
Blas Mola-Yudego

Bioenergy markets and policies
Lignoselluloosabiomassat ja niiden energiakäyttö
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Plantations

"energy crops are this"

Farmers, practitioners, agronomist and foresters perspective, production, technology, biology
Management

Cut-back

Harvesting

Cutback machine (CRL) on reverse drive tractor

Continuous bundler (Salix Maskiner)

Boyd, J; Christersson, L; Dinkelbach, L. Growing energy from willow The Scottish Agricultural College, 2000
Plantations

Willow (Salix) has been cultivated as an agricultural crop for bioenergy purposes in Sweden for the last twenty years and is regarded as an important crop for the production of wood fuel for the Swedish energy sector.

During the last two decades, more than 14 000 ha of short rotation willow plantations have been established in Sweden, i.e. about 0.5% of the total arable land in Sweden, making Sweden the leader in commercial plantations of short rotation willow in Europe.
Plantations

Policy maker perspective, goals, objectives, shares

"energy crops are this"
Transition

Natural Science
Technology
Biology
Engineering

Social Science
Economics
Social studies
Policy making
Reaching the goal

<table>
<thead>
<tr>
<th>Natural Science</th>
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<tbody>
<tr>
<td>Efficiency</td>
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<tr>
<td>Management</td>
<td>Policy incentives</td>
</tr>
<tr>
<td>Clonal material</td>
<td>Profitability</td>
</tr>
</tbody>
</table>

Yield: $\text{odt/ha yr}$

Total area planted: $\text{ha}$

$\text{toe, kwh, MJ}$
Policy Tools

1970s: Oil crisis, Swedish government ration gasoline and heating oil

1970: Research grants and investments on bioenergy developments. Includes plantations.

1980s: First commercial plantations

1980-1990s: Plan for de-regulation of Swedish agricultural sector

1990s: Programmes for economic/policy incentives for plantations

1995: Sweden joins the EU. CAP implemented
Policy Tools

Swedish measures to encourage Willow cultivation

a) SUBSIDIES
1991-1996: Generic subsidy of **1200 EUR/ha** for farmers that would change from cereal to other activities
1991-1996: **1330 EUR/ha** specific for willow production
+ **530 ECU** for fencing

b) TAXATION
Taxes on sulphur and CO₂ in heat production increased.
(biofuels exempted)
Plan & goal

Policy incentives

Subsidies
Taxes
Promotion
Research (public)

(Expressed in e.g. goals, objectives and plans)

Figure 2: Salix in Sweden: Scenarios versus reality


Plan & goal

Target for share of energy from renewable sources in final consumption of energy, 2020
Policy Effects
Meanwhile in UK…

1990s

2000s
Instruments

Coordination?
Dynamics of adoption

Penetration of Target Market

- Early adopters
- Innovators
- Early majority
- Late majority
- Laggards

Time
Dynamics of adoption

[Graph showing the dynamics of adoption in Örebro with a sigmoidal curve and observed data points.]
Dynamics of adoption

Aggregated Ha planted

Enköping

Aggregated number of adopters

Örebro

Aggregated Ha planted

1994

Dynamics of adoption
Dynamics of adoption

![Graph showing the dynamics of adoption over time with observed values and incentives with and without incentives. The graph includes a vertical line indicating the year 1991 when a new agricultural policy was introduced.](image-url)
Spatial dynamics of adoption
Time & Spatial dynamics of adoption

1986-1990

1991-1996

1997-2005

Dynamics of adoption

[Diagram showing the dynamics of adoption with data from 1986 to 2005, highlighting the year 1996 and the power plant's wood consumption.]
Dynamics of adoption
Dynamics of adoption

[Map and graph showing the dynamics of adoption with data points for 1986 to 2005, indicating GWh power plant (wood consumption) with ha planted by new growers and planted by experienced growers.]
Adoption: profiling

*Table 9: Influence on Salix activity from certain farm characteristics*

<table>
<thead>
<tr>
<th>positive influence</th>
<th>negative influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Size</td>
<td>Pasture</td>
</tr>
<tr>
<td>Forest land</td>
<td>Tenancy</td>
</tr>
<tr>
<td>Lease to others</td>
<td>Owner very young or very old</td>
</tr>
<tr>
<td>Owner age 50-65</td>
<td>Animal husbandry</td>
</tr>
<tr>
<td>Institutional owner</td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
</tr>
<tr>
<td>Mechanization</td>
<td></td>
</tr>
</tbody>
</table>
Adoption: Economics

The economics of adoption

Table 7: Comparison for Salix plantations in Northern Ireland between pioneer costs and cost projections based on more mature Swedish experience.

<table>
<thead>
<tr>
<th>Cost factors</th>
<th>Costs for pioneer grower</th>
<th>Cost projections based on Swedish experience</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GBP/ha/year&lt;sup&gt;24&lt;/sup&gt;</td>
<td>GBP/ha/year</td>
</tr>
<tr>
<td>Establishment</td>
<td>158</td>
<td>100</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Fertilisation spreading (high)</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>Fertilisation spreading (low)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Road transports</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td>Harvest</td>
<td>114</td>
<td>88</td>
</tr>
<tr>
<td>Field transports</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Administration</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Winding up</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Sum of costs</strong></td>
<td><strong>437</strong></td>
<td><strong>349</strong></td>
</tr>
</tbody>
</table>

Reaching the goal

<table>
<thead>
<tr>
<th>Yield</th>
<th>Adoption</th>
<th>Total area planted</th>
</tr>
</thead>
</table>

**Natural Science**
- Efficiency
- Management
- Clonal material

\[
\text{odt/ha yr}
\]

**Social Science**
- Adoption studies
- Policy incentives
- Profitability

\[
\text{ha}
\]
Reaching the goal: model

- Market Forces:
  - Demand
  - Opportunity costs
  - Alternatives

- Adoption

- Total area planted

- Yield

- Local perceptions and attitudes
Interactions

**Management:** 4 categories of equal number of growers, according to their performance (I, II, III, IV)

**Site areas:** using the local production of cereal as indicator

**Experience:**
The plantations were classified according to the previous experience of the grower

**PRODUCTION CHANGES**
Auto-correlation... aka “experience”

Farmers Learn!

It is often forgotten that in a new technology, there is a learning curve that will affect the final outcome.
Improvements

Trends of SRF productivity

- New varieties
- Experienced farmers
- Better overall methods
Productivity change

Best growers, changes in 10 years
Reaching the goal: model

Market Forces:
- Demand
- Opportunity costs
- Alternatives

Local Factors:
- Climate
- Soil

Biotic events
- Pests
- Diseases

Management:
- Local practices
- Local experience
- General improvements

R & D:
Innovations:
- New varieties
- Global Experience
- Efficiency

Yield

Adoption

Total area planted

Economy of Scale

Local perceptions and attitudes

Yield

Adoption

Total area planted

Economy of Scale

Local perceptions and attitudes

Yield

Adoption

Total area planted

Economy of Scale

Local perceptions and attitudes
The concept of Risk

Figure 5: Prices of wood chips in Sweden from 1985 to 2002.\textsuperscript{26}
Figure 2: Salix in Sweden: Scenarios versus reality


Goal fail?
Local perceptions and attitudes

Market Forces:
- Demand
- Opportunity costs
- Alternatives

Local Factors:
- Climate
- Soil

Biotic events
- Pests
- Diseases

Management:
- Local practices
- Local experience
- General improvements

R & D:
Innovations:
- New varieties
- Global Experience
- Efficiency

Yield

Total area planted

Profitability

Total production costs

Wood chip prices

Policy

Complexity!
Towards new business models
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Agroforestry

Simultaneous cultivation of plantations and annual crops on the same area

Picture sources: © Dominik Rutz
Agroforestry

*Border areas, stripes and landscape*

Picture sources: © Dominik Rutz
Averages of $\text{NO}_3^-$-N and $\text{PO}_4^-$-P concentrations in the groundwater of all fields pooled together for willow SRC and reference fields for the whole experimental period.
Impact on groundwater

- Leaching of NO$_3$-N in the groundwater is substantially lower from SRC

- Leaching of PO$_4$-P in the groundwater is slightly higher from SRC

- Leaching of PO$_4$-P in the groundwater was not correlated to sewage sludge applications
Impact on groundwater
Impact on soil

Relative differences between willow SRC plantations versus the reference. The values are the averages for all the locations of the different soil quality parameters investigated in topsoil (0-20 cm) and in subsoil (40-60 cm). Positive values represent higher observations of the studied parameter in the willow SRC plantations, in percentage (Dimitriou et al 2012, Bioenergy Research).
Impact on soil

- C storage in soil organic matter is higher under SRC than under conventional agricultural crops

- Soil organic matter stability is higher under SRC than under conventional agricultural crops and supports C sequestration in the soil

- Cd concentrations in the soil under SRC are lower than under conventional agricultural crops (ca. 12% lower in topsoil)

- Sludge applications did not affect the above differences of Cd in topsoil
Soil remediation
Biodiversity
Biodiversity
Biodiversity
Plantations vs agriculture

Figure 17. Impacts of willow short rotation cultivation on different environmental and socioeconomic factors. The line compares a scenario with 20% of the area planted (catchment level) to a reference level with no plantations (bold line).

Multifunctional uses: Enköping

SRWC plantations (76 ha)

Wastewater storage ponds

Wastewater treatment plant (20000 pe)
Irrigated Salix

Leachate ponds

Högbytorp landfill site, Upplands Bro

Photo: Ragnsells Avfallsbehandling AB
TEST

Blas Mola - Yudego (blas.mola@uef.fi)

Dr. I. Dimitriou, Dep. of Crop
Multifunctional uses: Enköping

Need: 50% N reduction in outflow (Municipality)
Solution: Reduced load of the water flow through:

1. Septic-tank sludge to rural storage ponds
2. Diversion of wastewater from dewatering of sewage sludge…
…and irrigation of willows with “wet sludge” and treated wastewater
Multifunctional uses: Enköping

300 km drip irrigation tubes

4/7/2000
Multifunctional uses: Enköping

Lined ponds for winter storage
Multifunctional uses: Enköping
Multifunctional uses: Enköping

- N, P, TOC leaching in groundwater
- Retention capacity vs maximum amounts applied
- Economic calculations and potential
Metalcycle in Enköping CHP-plant

Salix uptake from ground:

Cd: 9.8 g/ha yr
Cu: 55
Cr: 41
Hg: 0.34
Ni: 28
Pb: 9.86
Zn: 731

Cd: 0.75 g/ha yr
Cu: 194.5
Cr: 26.1
Hg: 0.33
Ni: 12.9
Pb: 15
Zn: 324

Cd: <1.1 g/ha yr
Cu: 183
Cr: <13
Hg: <0.4
Ni: 25
Pb: 13
Zn: 341

120 ha willowfield
76 ha willowfield

Irrigation project
200 000 m³/year

Total fuel input: 350 GWh

Chips
Sawdust
Salix
Bark

Ash/sludge mix

100%

Bottom ash

Depositio

100%

Electrostatic precipitator

Flue-gas condenser

Cd: 10%
Cu: 50%
Cr: 60%
Hg: 20%
Ni: 30%
Pb: 20%
Zn: 20%

Cd: 90%
Cu: 50%
Cr: 40%
Hg: 80%
Ni: 70%
Pb: 80%
Zn: 80%

Enköping river

Condensed water 30 000 m³/year

Clean water 3.8 mil. m³/year

Digested sludge
Wastewater treatment plant
Treated water + sludge water

Condensed water

Irrigation project

Chips
Sawdust
Salix
Bark

Ash/sludge mix
200 000 m³/year

100%

Electrostatic precipitator

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Cd: 10%
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Zn: 80%

Enköping river
Enköping model

“Positive attitudes” from local/regional authorities

Sewage plant operator

“Catalyst”
- Advisers

Mutual agreements

Heat & power plant operator

“Catalyst”
- Advisers from companies specialized in willow production

Farmer
Profitability

Table 1. Gross margin of SRC (EUR/ha) for a range of yields and wood chip prices (for Swedish conditions in 2009; 1 MWh = 3.6 GJ, 1 t DM = 15.8 GJ). In: Dimitriou and Rosenqvist (2011).

<table>
<thead>
<tr>
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<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
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<tbody>
<tr>
<td>4</td>
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<td>185</td>
<td>235</td>
<td>285</td>
<td>335</td>
<td>385</td>
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</tr>
</tbody>
</table>

Table 2. Gross margin for SRC cultivation when sewage sludge is applied (EUR/ha) for a range of yields and wood chip prices (Swedish conditions, 1 MWh = 3.6 GJ, 1 t DM = 15.8 GJ). In: Dimitriou and Rosenqvist (2011).

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<tr>
<td>2</td>
<td>-263</td>
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<td>274</td>
<td>327</td>
<td>380</td>
<td>432</td>
<td></td>
</tr>
</tbody>
</table>

Fertilized sewage sludge
# Profitability

Table 1. Gross margin of SRC (EUR/ha) for a range of yields and wood chip prices (for Swedish conditions in 2009; 1 MWh = 3.6 GJ, 1 t DM = 15.8 GJ). In: Dimitriou and Rosenqvist (2011).

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<td>335</td>
<td>385</td>
</tr>
</tbody>
</table>

Table 3. Gross margin for a range of yields and wood chip prices (EUR/ha) for SRC cultivation when irrigation with wastewater occurs (Swedish conditions, 1 MWh = 3.6 GJ, 1 t DM = 15.8 GJ).

<table>
<thead>
<tr>
<th>Price (€/GJ)</th>
<th>Yield level (t DM/ha)</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
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<td>-256</td>
<td>-264</td>
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<td>-278</td>
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<td>-293</td>
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<td>3</td>
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<td>-137</td>
<td>-131</td>
<td>-126</td>
<td>-120</td>
<td>-114</td>
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<tr>
<td>4</td>
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<td>5</td>
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<td>61</td>
<td>80</td>
<td>98</td>
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<td></td>
<td>72</td>
<td>103</td>
<td>135</td>
<td>167</td>
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<td>262</td>
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<td>221</td>
<td>266</td>
<td>311</td>
<td>355</td>
<td>400</td>
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<td>7</td>
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<td>280</td>
<td>338</td>
<td>396</td>
<td>454</td>
<td>512</td>
<td>570</td>
<td>628</td>
<td>686</td>
</tr>
</tbody>
</table>

![Graph showing irrigation with wastewater]
Multifunctional uses: Anywhere

*Spreading of sewage sludge and wood-ash (when available)*
Soil salinization management

Trees and shrubs can be used to address soil salinity by reducing groundwater recharge, either by using water in the root zone and reducing ‘leakage’ to deeper aquifers; or by reducing saline or potentially saline groundwater levels (make them deeper beneath the ground surface) through roots directly accessing the water table and increasing discharge.
New business models

Table 2: Some important externalities from Salix plantations on mineral soils.

<table>
<thead>
<tr>
<th>Externality</th>
<th>Assumptions</th>
<th>Economic value (SEK/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon sink.</td>
<td>Value: 180 USD per ton carbon reduction</td>
<td>14</td>
</tr>
<tr>
<td>Reduced nitrogen leaching.</td>
<td>50% reduction of leaching.</td>
<td>9</td>
</tr>
<tr>
<td>Reduced nitrogen leaching.</td>
<td>Value: 5.5 USD per kg N.</td>
<td></td>
</tr>
<tr>
<td>Heavy metal removal.</td>
<td>Removal of 8 g Cd / ha / year.</td>
<td>4</td>
</tr>
<tr>
<td>Heavy metal removal.</td>
<td>Value: 4.2 USD per g Cd, equivalent to Swedish tax on cadmium-polluting fertilisers.</td>
<td></td>
</tr>
<tr>
<td>Biodiversity.</td>
<td>Effect is uncertain and difficult to assess in economic terms.</td>
<td></td>
</tr>
</tbody>
</table>

Total: 27
### Table 3: Opportunities for combined use of Salix plantations

<table>
<thead>
<tr>
<th>Combined use</th>
<th>Assumptions</th>
<th>Economic value (SEK/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Waste water treatment.</strong>&lt;br&gt;Salix plantations in close proximity of villages or towns can be used to filter municipal waste water, removing 75-95% of nitrogen and phosphorus. This reduces the municipal need for chemical treatment of waste water and the farmers need for fertiliser.</td>
<td>Town of less than 50,000 inhabitants. Municipal cost savings of 7 USD/kg N and improved farm economics of 180 USD/ha. (Benefits can be significant also in larger towns)</td>
<td>29 112</td>
</tr>
<tr>
<td><strong>Re-circulation of sewage sludge.</strong>&lt;br&gt;Salix plantations at a greater distance from population centres can be used to deposit sewage sludge.</td>
<td>Avoided deposit costs of 80 USD/tonne sludge and improved farm economics of 110 USD/tonne.</td>
<td>18 13</td>
</tr>
<tr>
<td><strong>Hunting.</strong>&lt;br&gt;Increased bio diversity can provide improved opportunities for hunting, especially if the layout and operation is somewhat modified for this purpose.</td>
<td>Economic assessment is difficult, before more experience is available.</td>
<td></td>
</tr>
<tr>
<td>Policy maker’s view</td>
<td>Farmers view</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td><strong>Policy maker’s view</strong></td>
<td><strong>Farmers view</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Policy concerns</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>biological productivity</td>
<td>+++ essential policy aim, even beyond short‐term cost‐effectiveness</td>
<td>++ important aim, but only if cost‐efficient</td>
</tr>
<tr>
<td>keeping down the use of fertilisers and pesticides</td>
<td>++ important in relation to goals for sustainable agriculture</td>
<td>+ only important if cost‐efficient</td>
</tr>
<tr>
<td>creating a stable market or planting stock and services</td>
<td>++ important for creating a viable supply sector, and for effective use of R&amp;D funding</td>
<td></td>
</tr>
<tr>
<td>addressing a variety of soil types and geography</td>
<td>++ important for the future large scale use of Salix</td>
<td></td>
</tr>
<tr>
<td>promoting interest among end users</td>
<td>++ important for reducing subsidy requirements</td>
<td></td>
</tr>
<tr>
<td>policy stability</td>
<td>++ important to avoid confusion in the market</td>
<td>++ change of rules is a burden in itself</td>
</tr>
<tr>
<td><strong>Farmers concerns</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>competitive income compared to alternatives</td>
<td>+ desirable for the reduction of subsidies, but only important in the longer term</td>
<td>+++ key reason to grow a crop</td>
</tr>
<tr>
<td>stable and predictable incomes</td>
<td>+ desirable for continuity of learning processes, and for acceptance of CAP reform</td>
<td>++ important for long‐term commitment</td>
</tr>
<tr>
<td>sharing of production risks</td>
<td>– best that farmers have the full production risk, as this maximise incentives for good farm management</td>
<td>++ valuable in particular for inexperienced farmers or farmers with a tight economic situation</td>
</tr>
<tr>
<td>sharing of energy price risks</td>
<td>++ a good allocation of this risk is important to keep down subsidy requirements</td>
<td>+++ essential to avoid large risk exposure, that is beyond the farmers capacity for analysis or risk management</td>
</tr>
<tr>
<td>no hindrance for sale or retirement</td>
<td></td>
<td>+++ essential for older farmers</td>
</tr>
<tr>
<td>gradual expansion possible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>avoid liquidity problems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>involvement of advisors, bankers and end users in decision making</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 11: Summary of policy concerns seen from two different views**

Note: * ++ +++ (or similar negative symbols) indicate the degree of attachment to the aims.
Effective trade-offs between the different alternatives and objectives to be found

A set of compatible trade-offs alternatives will be consulted by the different stakeholders and decision makers

In the end, a double assessment will be delivered: a quantitative analysis resulting in a set of efficient alternatives for each zone, and a qualitative analysis resulting in an assessment of each of the selected alternatives by experts and stakeholders.
Erosion, leaching

- Municipality
- Biogas plant
- Crop rotation with maize
- Arable fields
- Preference areas
- Flood prone area
- Biotope
- WPA
- FFH

Combination of erosion protection and enhancing (bio)diversity

Reduce increasing erosion risk due to maize

Buffer strips could reduce sediment load

Case study: G Busch, BALSA
Erosion, leaching

Case study: G Busch, BALSA

Land cover classes:
- Residential area
- Arable land
- Pasture
- Woods
- Dec. forest
- Conf. forest
- Mix. forest
- Water
- Municipality border

Friedland, Germany

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Datengrundlagen:
DLM-25 ATKIS, 2006 - DTK100, LGN 2011