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Bioenergy yield from cultivated land in Denmark - competition between food, bioenergy and fossil fuels under physical and environmental constraints

Callesen, Ingeborg; Grohnheit, Poul Erik; Østergård, Hanne

Published in:
Collection of extended abstracts

Publication date:
2011

Bioenergy yield from cultivated land in Denmark – competition between food, bioenergy and fossil fuels under physical and environmental constraints

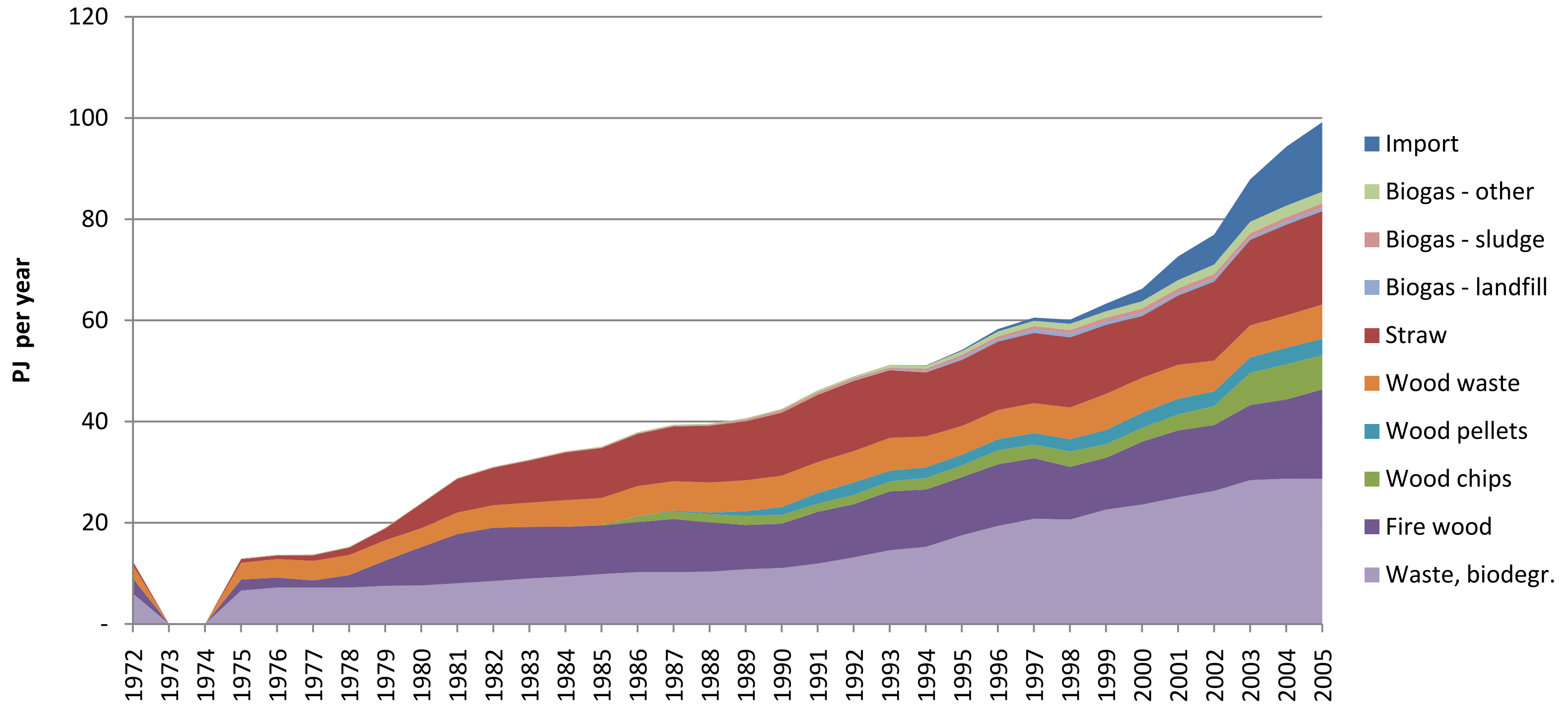
[1,2]Ingeborg Callesen, [2]Poul Erik Grohnheit and

[2]Hanne Østergård

[1] DTU-Man, [2] Risø-DTU

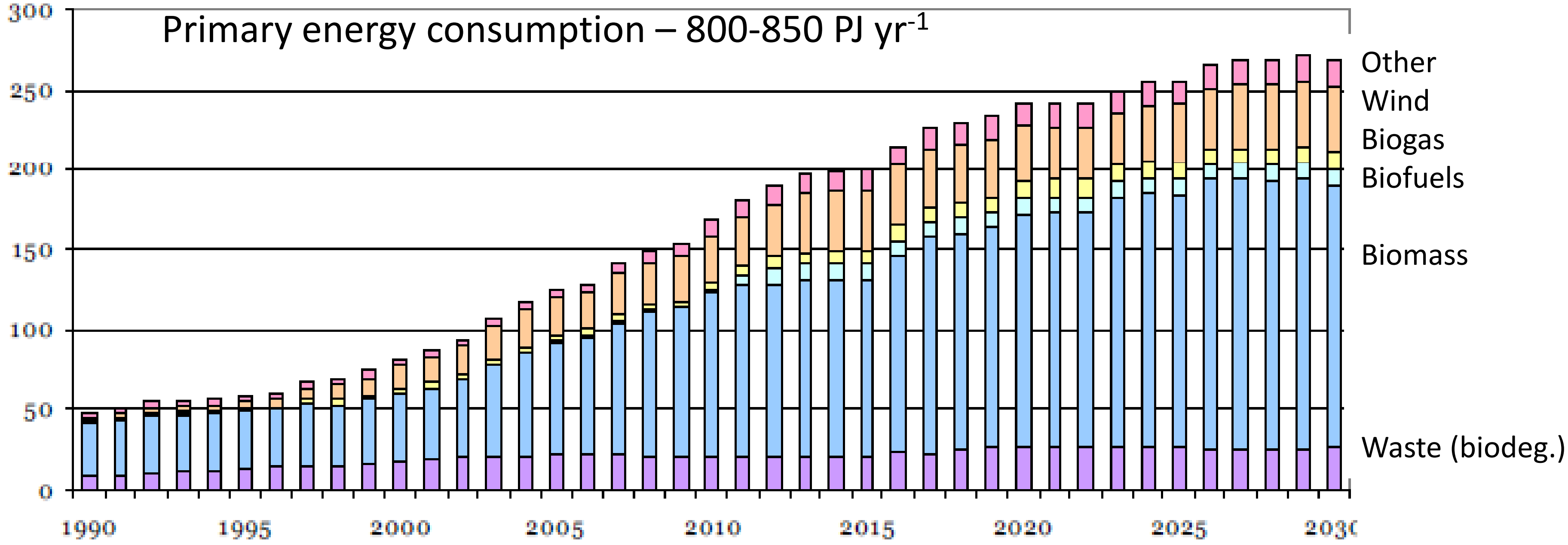
International Conference on Energy, Environment and Health
– Optimisation of Future Energy Systems
May 31-June 2, 2010
Carlsberg Academy, Copenhagen, Denmark

Bioenergy past



Danish Energy Agency, 2006

Renewable energy future

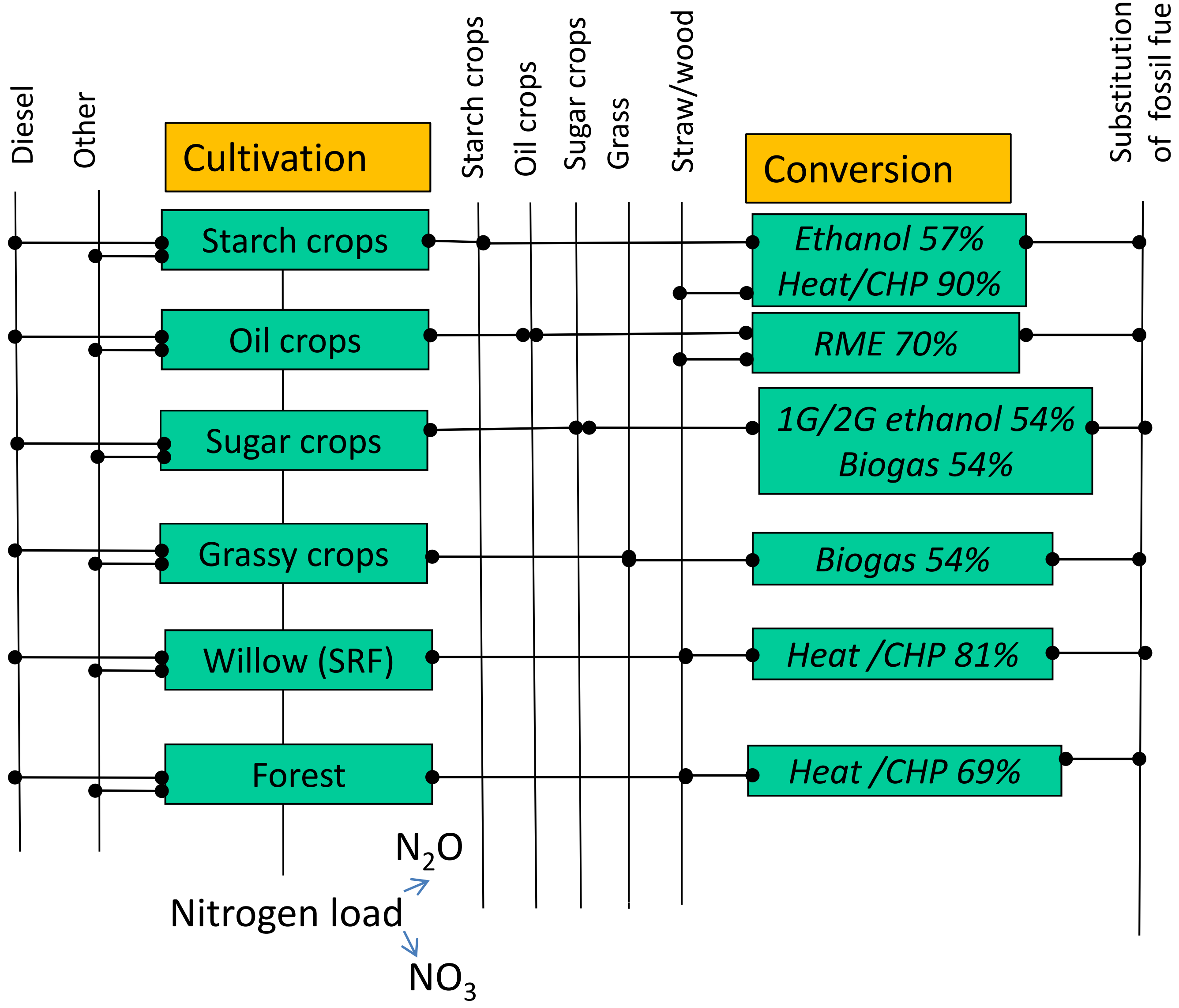


Danmarks energifremskrivning frem til 2030
[Energy projection to 2030]
Danish Energy Agency, 2009

Domestic bioenergy ?

- What is the potential biomass supply in PJ yr^{-1}
- What is the monetary cost ?
- Energy efficiency?
- Land availability and suitability for annual crops, short rotation forest (willow) and plantation spruce forest ?
- Consequences for nitrogen load

Model overview



Model parameters

- Denmark, total area 4309 kha
- Amounts and costs of seeds, machine operations, pesticides, fuels, fertilisers and lime.
- Bioenergy conversion types: district heating, heat and power, biogas, biodielsel (RME), bioethanol (data from AEBIOM, 2005)

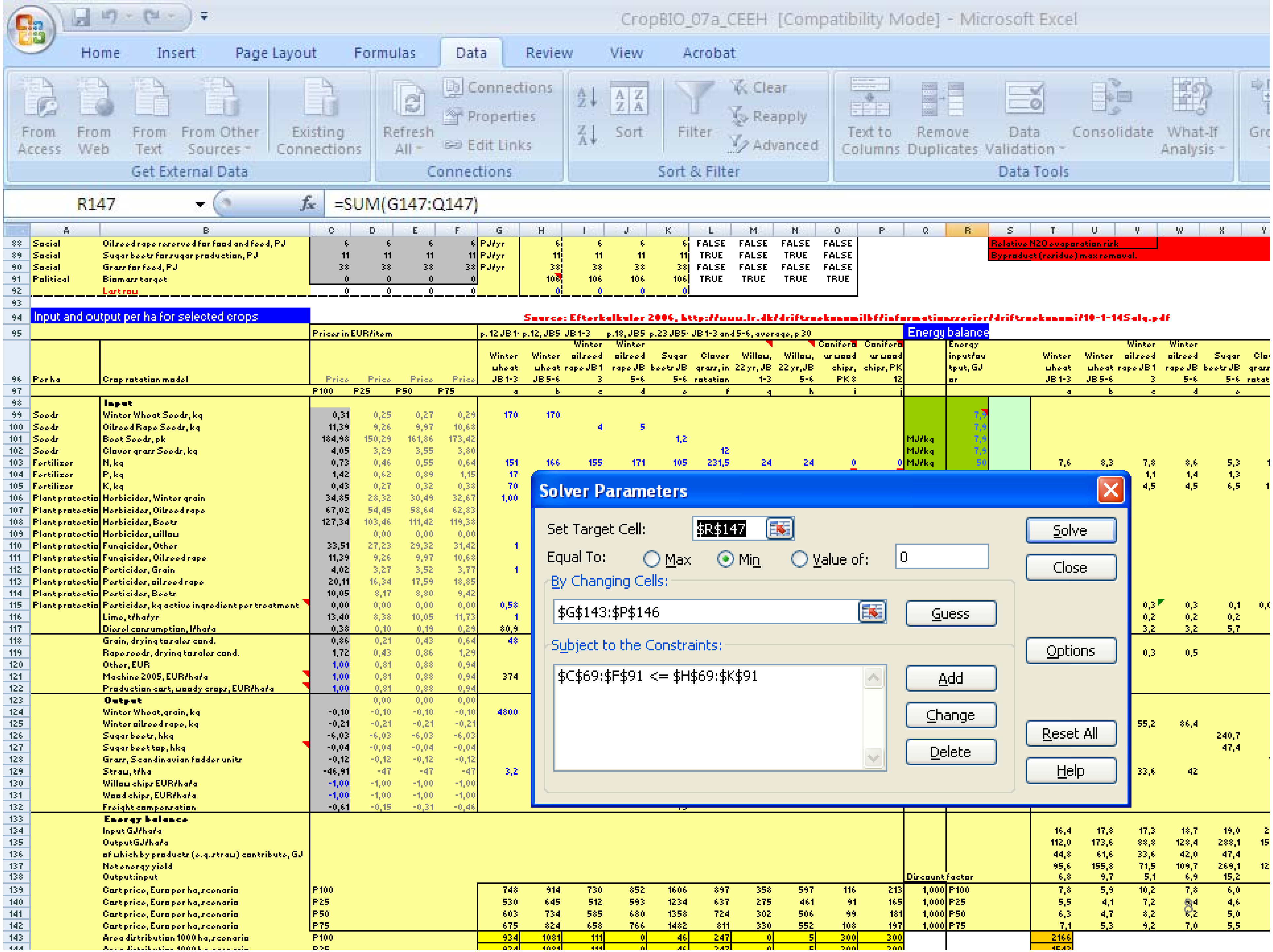
Minimize fuel cost

- Cost minimization model
- Linear programming – a technique developed within operations research
- Objective function: Min Y = cX
- Constraints: aX <=b, X>=0, X~X_1-X_n

- Energy mix of bioenergy and diesel oil

$$\min_{a} \sum_{i} \{ \; p_{ic(oil)} \times x_{itc} \times a_{it} + p_{oil} \times (E - E_{bio}) \; \}$$

a~area, i~crop representative, c~commodity, t~soil type, oil~oil price

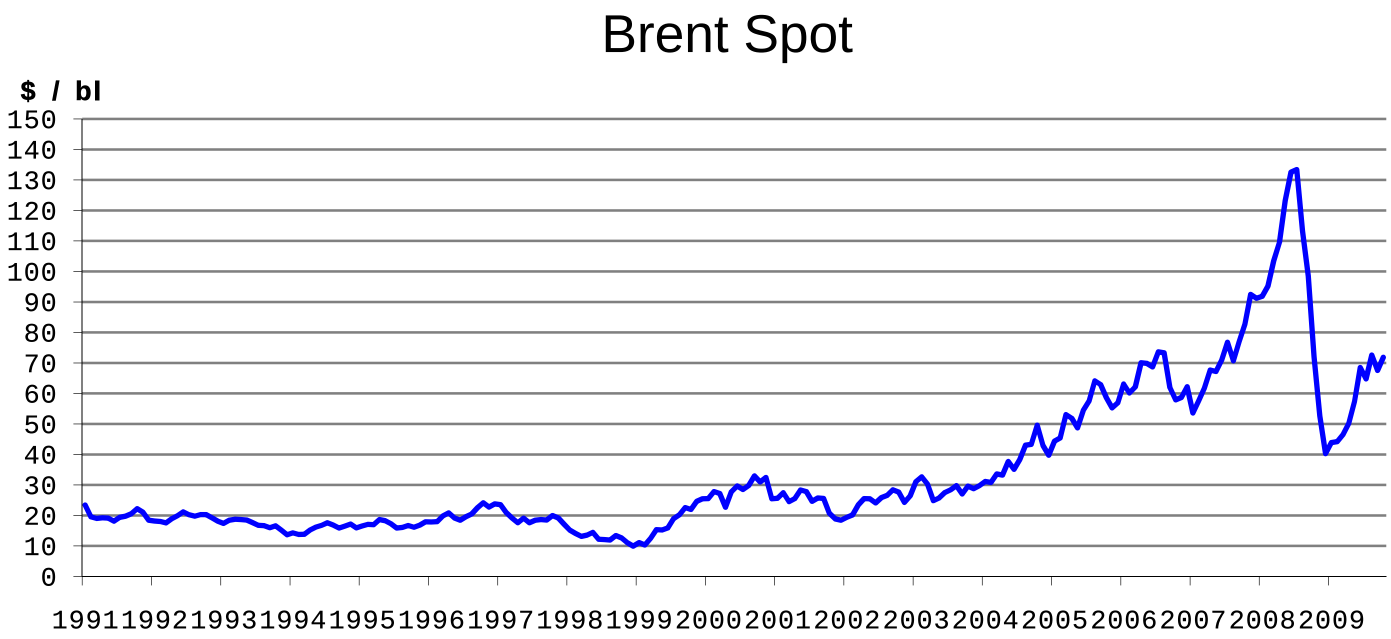

CropBIO_07a_CEEH [Compatibility Mode] - Microsoft Excel
Home
Insert
Page Layout
Formulas
Data
Review
View
Acrobat
From Access
From Web
From Text
From Other Sources
Existing Connections
Get External Data
Refresh All
Connections
Properties
Edit Links
Connections
Sort
Filter
Clear
Reapply
Advanced
Sort & Filter
Text to Columns
Remove Duplicates
Data Validation
Consolidate
What-If Analysis
Data Tools
R147
=SUM(G147:Q147)
Input and output per ha for selected crops
Energy balance
Solver Parameters
Set Target Cell:
$R$147
Equal To:
Max
Min
Value of:
0
By Changing Cells:
$G$143:$P$146
Guess
Subject to the Constraints:
$C$69:$F$91 <= $H$69:$K$91
Add
Change
Delete
Solve
Close
Options
Reset All
Help

Model constraints I

- Physical
  - Cultivated land area 3200 kha (2005)
  - Forest area: 600 kha
  - Soil types: 48% sandy, 52% loamy
- Agronomy – crop rotations
  - e.g. oilseed rape every 4 years~max 25%
- Environmental: biodiversity ~area reservation for permanent grassland, limits on willow area

Oil price and commodity prices

- Oil price range from index 25 to index 200
  - Index 100 ~2005~9.4€ GJ^{-1}



Scenario constraints

Scenario A

Food & feed 100% (=2005)

Willow< 0.2% area

Permanent grass 175 kha

Type	Model constraints	P100
Physical	Cultivated land	3200
Physical	Minimum forest area	600
Physical	Maximum forest area PK 8	300
Physical	Maximum forest area PK 12	300
Landscape	Permanent grass (out of rotation)	175
Landscape	Maximum area of annual crops and SRF area	2425
Soil quality	JB 1-3 + JB 11 (humus) of land area.	1164
Soil quality	JB 4-10 and 12 (calcareous) of land area.	1261
Crop rotation	Rape seed area of annual crop land (loamy)	111
Crop rotation	Rape seed area of annual crop land (sandy)	0
Landscape	Minimum share of clover grass, in rotation	200
Landscape	Maximum area of SRF (willow), kha	5
Crop rotation	Area limitation on sugar beet (and soil quality)	46
Landscape and biodiversity	Crop mix, annual crops, sandy soils	934
Landscape and biodiversity	Crop mix, annual crops loamy soils	1081
Ground water	N leaching (k t N/yr)	180
GHG	N2O emission from cultivated land (kt N2O-N/yr)	8
Carbon balance - soil humus	Straw for feed/animal husbandry	18
Social	Timber/construction wood	5
Social	Wheat grain reserved for food and feed, PJ	167
Social	Oil seed rape reserved for food and feed, PJ	6
Social	Sugar beets for sugar production, PJ	11
Social	Grass for feed, PJ	38

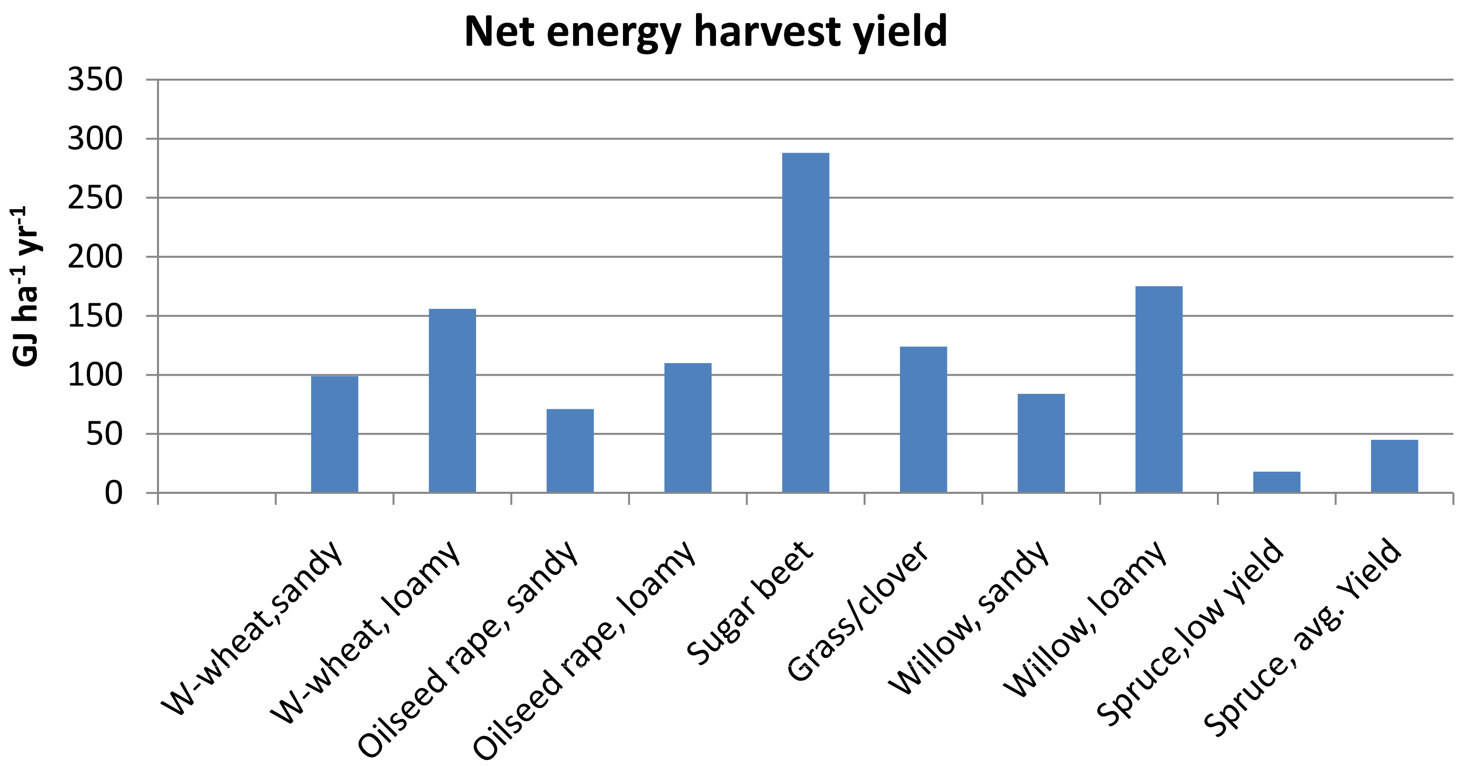
Scenario B

Food & feed 50% of scenario A

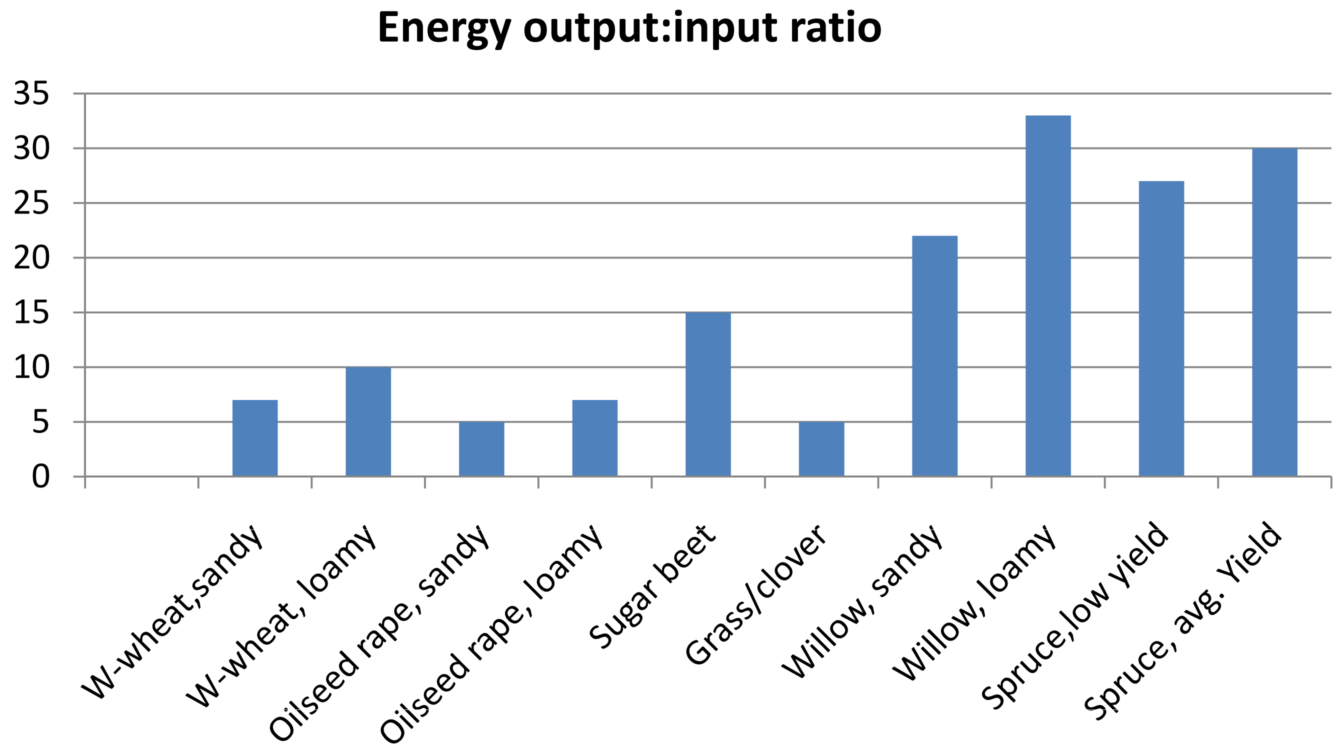
Willow< 25% area

Permanent grass 275 kha

Crop yields

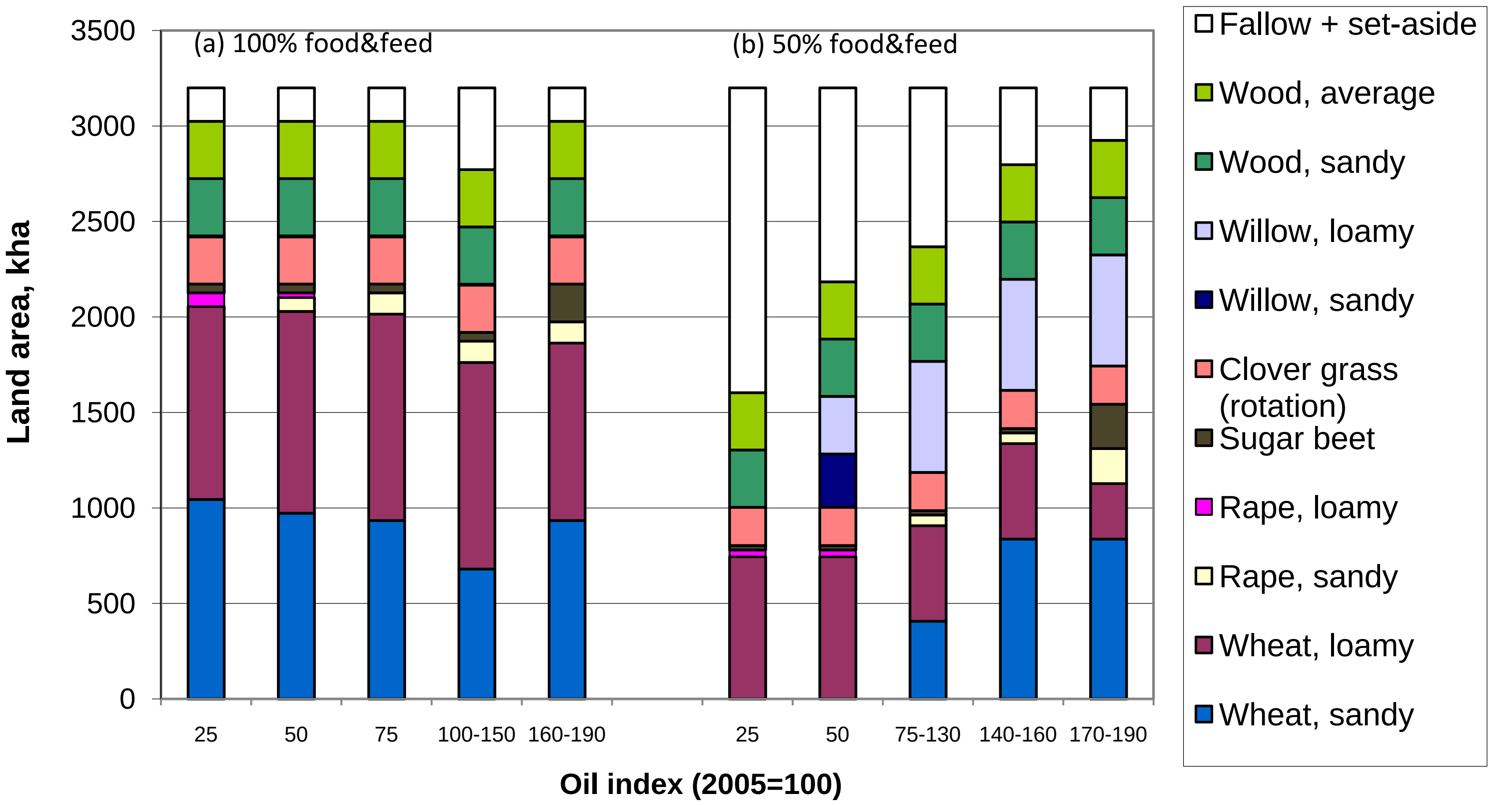


Net energy harvest yield
GJ ha-1 yr-1
350
300
250
200
150
100
50
0
W-wheat,sandy
W-wheat, loamy
Oilseed rape, sandy
Oilseed rape, loamy
Sugar beet
Grass/clover
Willow, sandy
Willow, loamy
Spruce,low yield
Spruce, avg. Yield

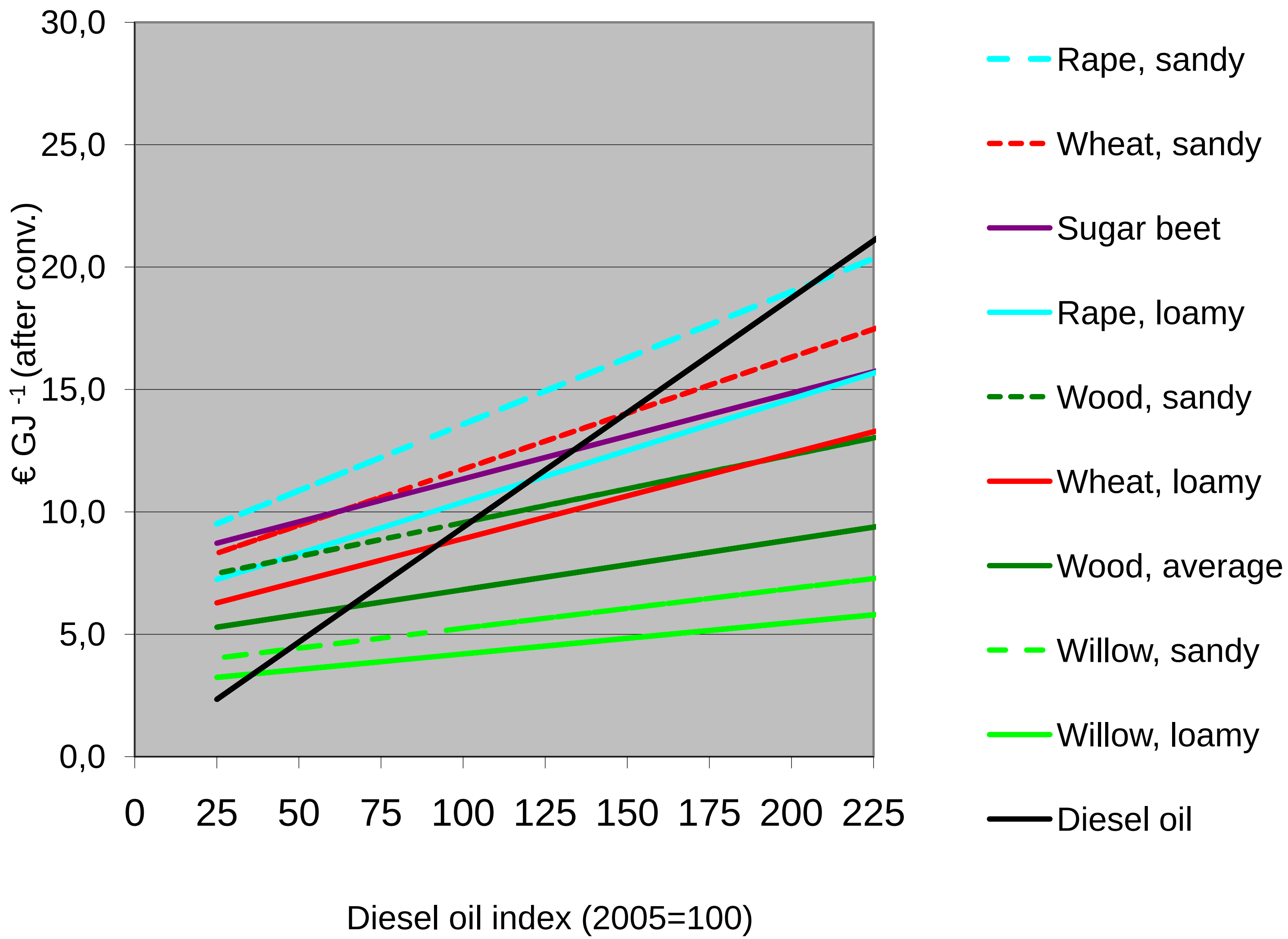


Energy output:input ratio
35
30
25
20
15
10
5
0
W-wheat,sandy
W-wheat, loamy
Oilseed rape, sandy
Oilseed rape, loamy
Sugar beet
Grass/clover
Willow, sandy
Willow, loamy
Spruce,low yield
Spruce, avg. Yield

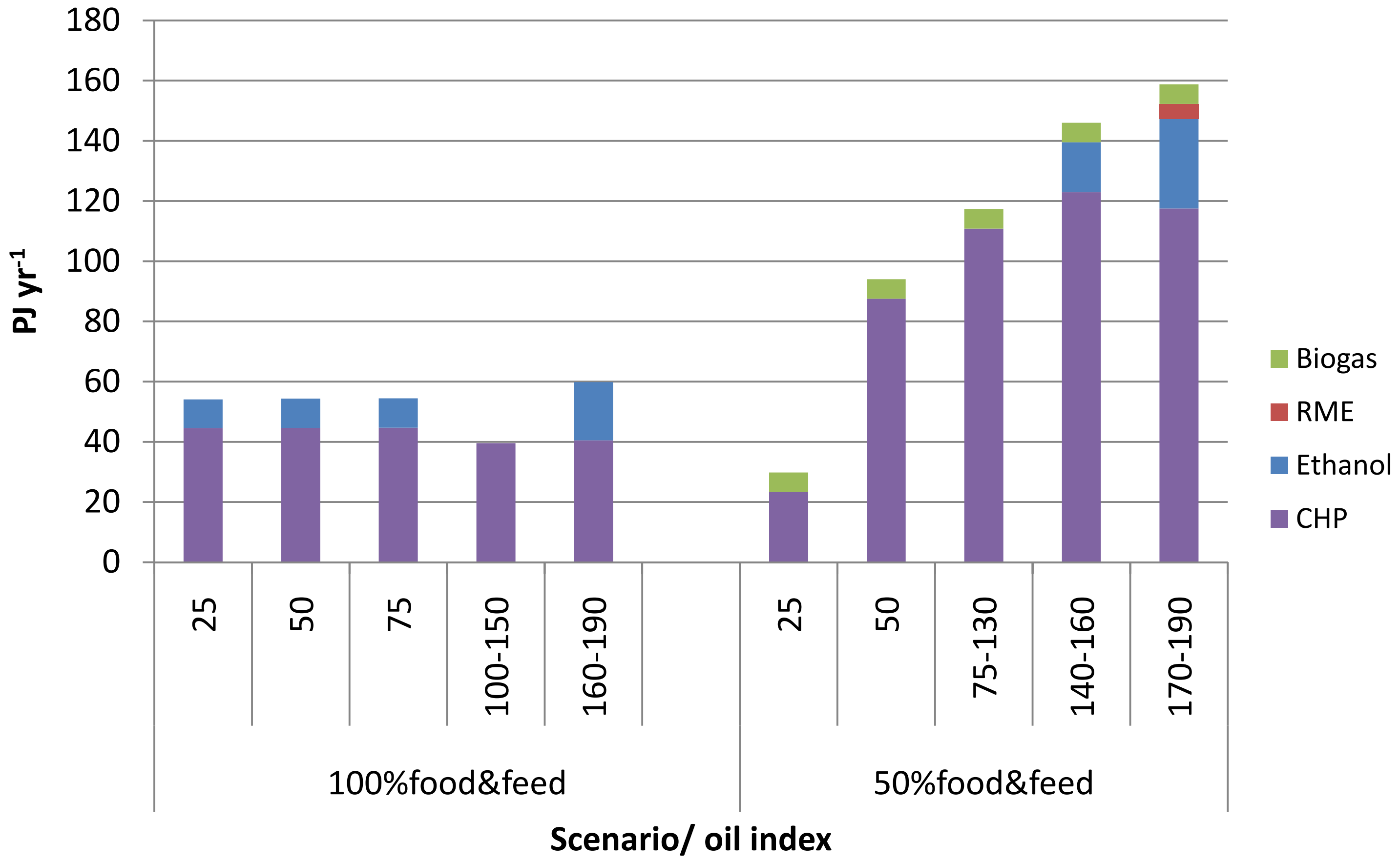
Crop area distribution



Biomass feedstock cost

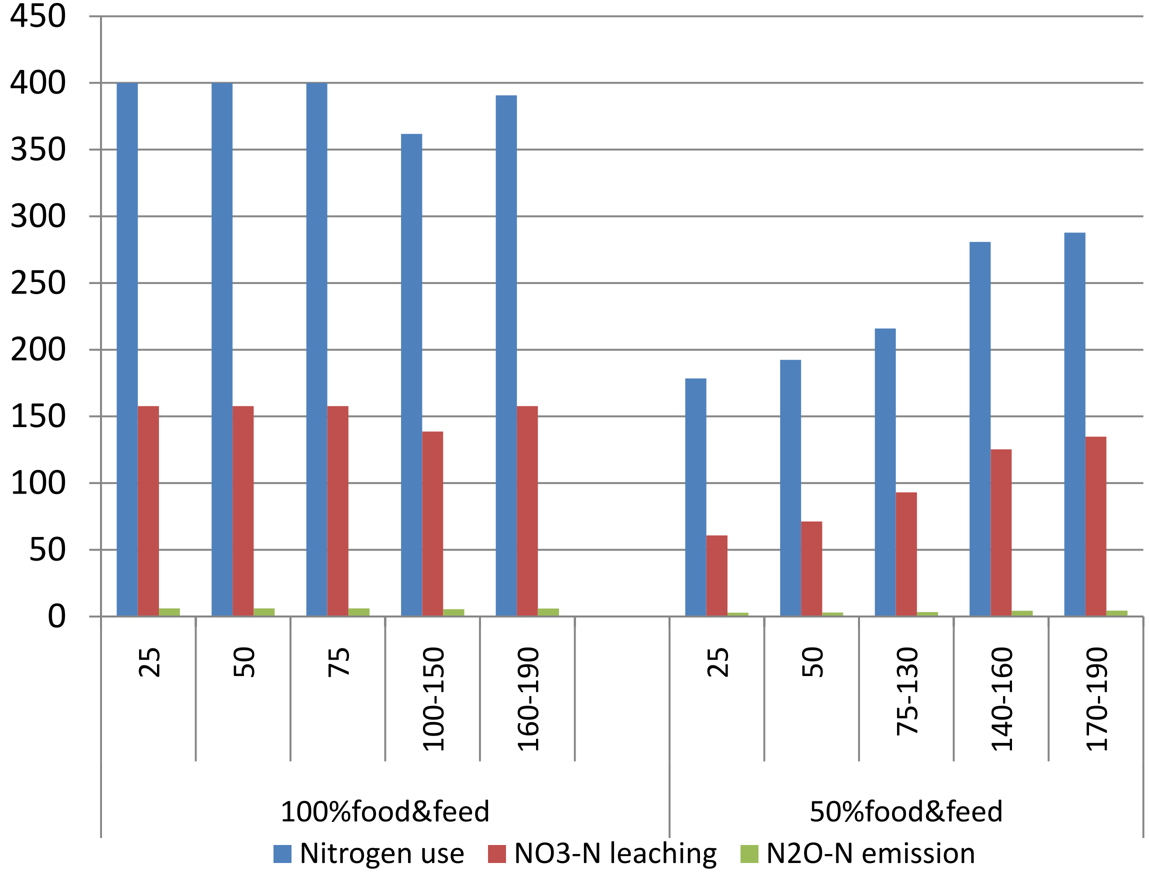


Bioenergy yield



Nitrogen load from cultivated land

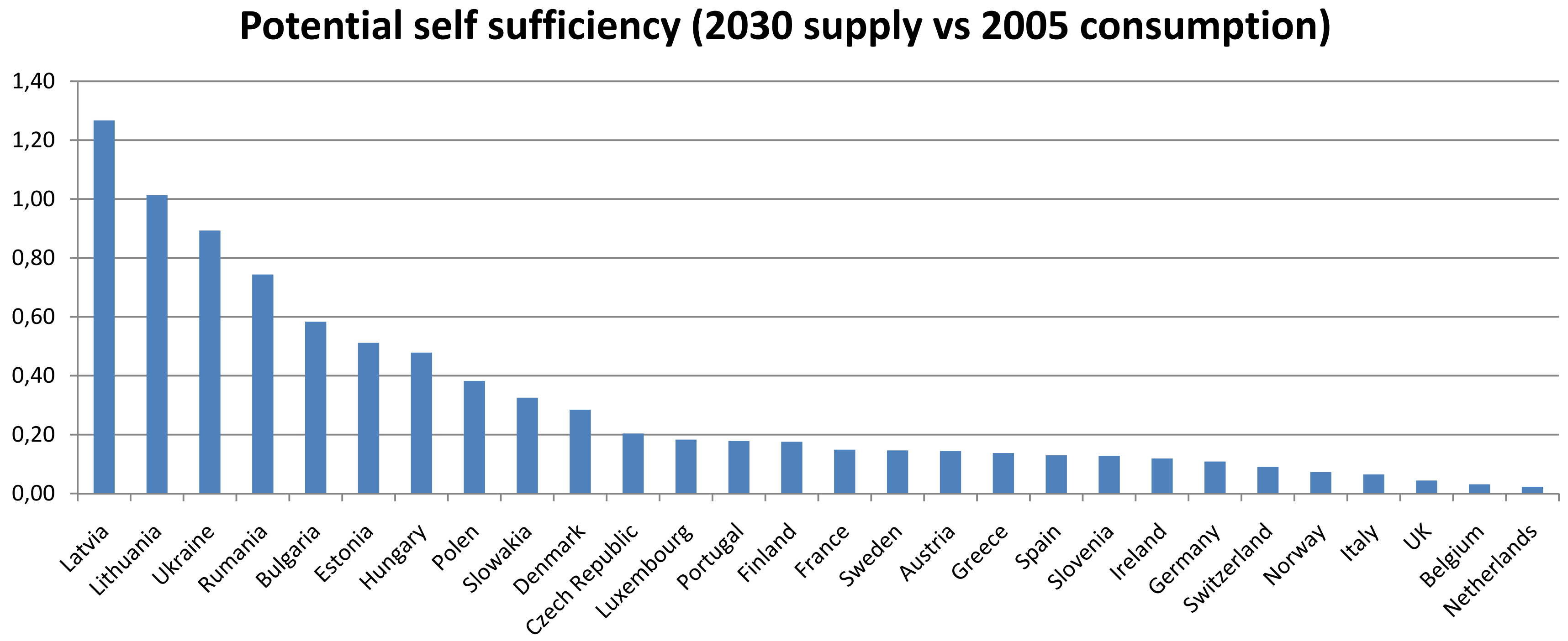
- Reduction in N use and thus in N leaching and in N_2O losses



Bioenergy future scenarios

Jørgensen, 2008	AGR	FOR	WASTE	TOTAL
		PJ yr^{-1}		
Current	5	25	19	50
Scenario	82	32	33	147
EEA, 2006	**AGR**	**FOR**	**WASTE**	**TOTAL**
2010	17	4	96	117
2030	4	8	92	105
Our study, Oil index 100	**AGR**	**FOR**	**WASTE**	**TOTAL**
100%FF	0	21	32	53
50%FF	6	125	18	149

Biomass in EU27



Total: 8 – 25 EJ yr^{-1}

After deWit et al. 2009, figure 6, Biomass & bioenergy
doi:10.1016/j.biombioe.2009.07.011
The Refuel project, www.refuel.eu

Conclusion

- More biomass for bioenergy at increasing oil prices
- Domestic bioenergy potentials are limited due to land and environmental constraints (~20% of primary energy use)
- Increased biomass imports necessary to meet strategic goals of bioenergy supply
- Large N load reductions possible by growing more short rotation forest (willow) or by planting high forest

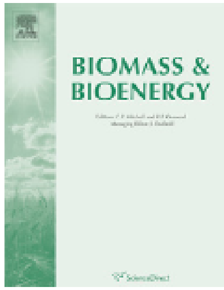
More about the model

ELSEVIER

Available at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe



Optimization of bioenergy yield from cultivated land in Denmark

Ingeborg Callesen [a,*], *Poul Erik Grohnheit* [b], *Hanne Østergård* [a]

[a] *Biosystems Division, Risø National Laboratory for Sustainable Energy, Technical University of Denmark – DTU, Building 301, P.O. Box 49, Frederiksborgvej 399, DK-4000 Roskilde, Denmark*

[b] *Systems Analysis Division, Risø National Laboratory for Sustainable Energy, Technical University of Denmark – DTU, Building 110, P.O. Box 49, Frederiksborgvej 399, DK-4000 Roskilde, Denmark*

doi:10.1016/j.biombioe.2010.04.020