



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

[Link back to DTU Orbit](#)

Citation (APA):
Callesen, I., Grohnheit, P. E., & Østergård, H. (2011). Bioenergy yield from cultivated land in Denmark - competition between food, bioenergy and fossil fuels under physical and environmental constraints. In *Collection of extended abstracts* (pp. 151-156). Centre for Energy, Environment and Health.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



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

^{1,2}Ingeborg Callesen, ²Poul Erik Grohnheit and

²Hanne Østergård

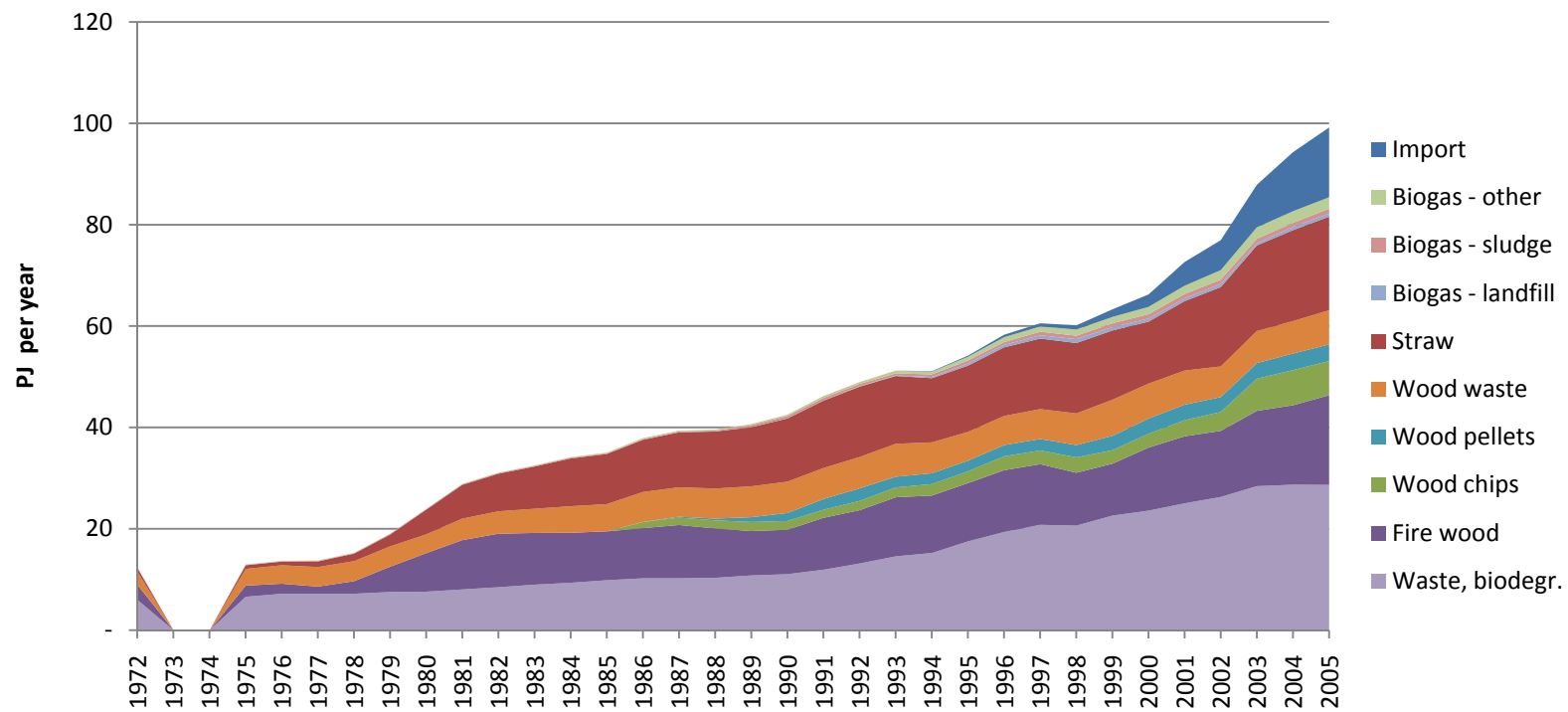
¹ DTU-Man, ² Risø-DTU

DTU Management Engineering
Department of Management Engineering

Section for Quantitative Sustainability Assessment

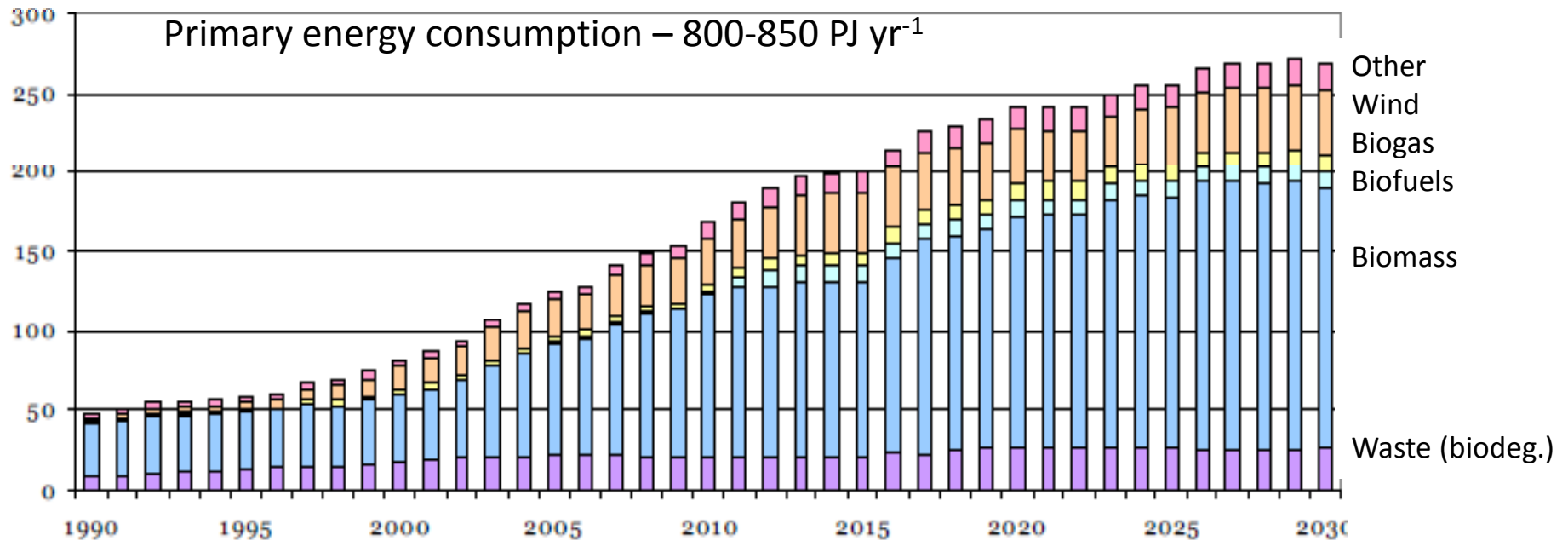
International Conference on Energy,
Environment and Health
– Optimisation of Future Energy Systems
May 31-June 2, 2010
Carlsberg Academy, Copenhagen,
Denmark

Bioenergy past



Danish Energy Agency, 2006

Renewable energy future



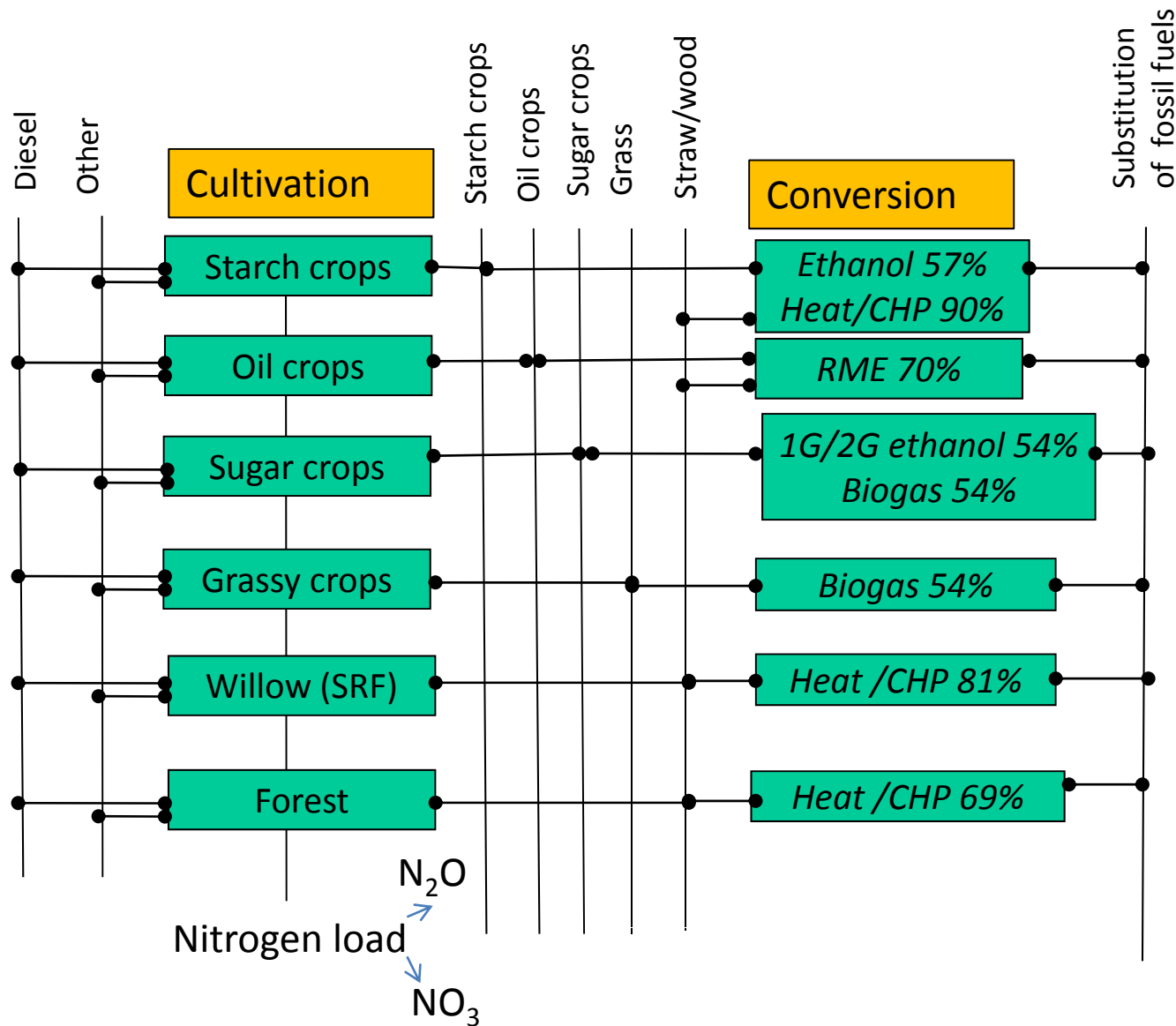
Danmarks energifremskrivning frem til 2030
[Energy projection to 2030]
Danish Energy Agency, 2009

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, biodiesel (RME), bioethanol (data from AEBIOM, 2005)

Minimize fuel cost



- Cost minimization model
- Linear programming – a technique developed within operations research
- Objective function: $\text{Min } Y = cX$
- Constraints: $aX \leq b, X \geq 0, X \sim X_1 - X_n$
- Energy mix of bioenergy and diesel oil

$$\min_a \sum_i \left\{ p_{ic(oil)} \times x_{itc} \times a_{it} + p_{oil} \times (E - E_{bio}) \right\}$$

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

Home Insert Page Layout Formulas Data Review View Acrobat

From Access From Web From Text From Other Sources Existing Connections Refresh All Connections Sort & Filter Filter Clear Reapply Advanced Text to Columns Remove Duplicates Data Validation Consolidate What-If Analysis

R147 =SUM(G147:Q147)

88	Social	Oilseed rape reserved for food and food, PJ	6	6	6	6	PJ/yr	6	6	6	6	FALSE	FALSE	FALSE	FALSE	Relative N2O emission risk
89	Social	Sugar beets for sugar production, PJ	11	11	11	11	PJ/yr	11	11	11	11	TRUE	FALSE	TRUE	FALSE	Byproduct (residue) max removal
90	Social	Graz for food, PJ	38	38	38	38	PJ/yr	38	38	38	38	FALSE	FALSE	FALSE	FALSE	
91	Political	Biomass target	0	0	0	0		108	106	106	106	TRUE	TRUE	TRUE	TRUE	
92		Lartrou	0	0	0	0		0	0	0	0					

94 Input and output per ha for selected crops Source: Efterskalkular 2006, <http://www.lr.dk/Driftsteknologi/Informationsserier/Driftsteknologi10-145slq.pdf>

95	Per ha	Crop rotation model	Price in EUR/item				Energy balance																
			P100	P25	P50	P75	Winter wheat JB 1-3	Winter wheat JB 5-6	Winter oilseed rape JB 3	Winter oilseed rape JB 5-6	Sugar beets JB 5-6	Claver grass rotation	Willow, 22 yr, JB 1-3	Willow, 22 yr, JB 5-6	Conifer wood chip, PK 8	Conifer wood chip, PK 12	Energy input/output	Winter wheat JB 1-3	Winter wheat JB 5-6	Winter oilseed rape JB 3	Winter oilseed rape JB 5-6	Sugar beets JB 5-6	Claver grass rotation
96							a	b	c	d	e	f	g	h	i	i		a	b	c	d	e	
97		Input																					
99	Seeds	Winter Wheat Seeds, kg	0,31	0,25	0,27	0,29	170	170															
100	Seeds	Oilseed Rape Seeds, kg	11,39	9,26	9,97	10,68			4	5													
101	Seeds	Beet Seeds, pk	184,98	150,29	161,36	173,42					1,2						MJ/ka						
102	Seeds	Claver grass Seeds, kg	4,05	3,29	3,55	3,90						12					MJ/ka						
103	Fertilizer	N, kg	0,73	0,46	0,55	0,64	151	166	155	171	105	231,5	24	24	0	0	MJ/ka						
104	Fertilizer	P, kg	1,42	0,62	0,89	1,15	17										MJ/ka		7,6	8,3			
105	Fertilizer	K, kg	0,43	0,27	0,32	0,38	70																
106	Plant protection	Herbicide, Winter grain	34,85	28,32	30,49	32,67	1,00																
107	Plant protection	Herbicide, Oilseed rape	67,02	54,45	58,64	62,83																	
108	Plant protection	Herbicide, Beet	127,34	103,46	111,42	119,38																	
109	Plant protection	Herbicide, willow	0,00	0,00	0,00	0,00																	
110	Plant protection	Fungicide, Other	33,51	27,23	29,32	31,42	1																
111	Plant protection	Fungicide, Oilseed rape	11,39	9,26	9,97	10,68																	
112	Plant protection	Fungicide, Grain	4,02	3,27	3,52	3,77	1																
113	Plant protection	Fungicide, oilseed rape	20,11	16,34	17,59	18,95																	
114	Plant protection	Fungicide, Beet	10,05	8,17	8,90	9,42																	
115	Plant protection	Fungicide, active ingredient per treatment	0,00	0,00	0,00	0,00	0,58																
116		Lime, t/ha/yr	13,40	8,38	10,05	11,73	1																
117		Diesel consumption, l/ha	0,38	0,10	0,19	0,29	30,9																
118		Grain, drying tazelet cand.	0,86	0,21	0,43	0,64	48																
119		Rape seeds, drying tazelet cand.	1,72	0,43	0,86	1,29																	
120		Other, EUR	1,00	0,81	0,88	0,94																	
121		Machine 2005, EUR/ha	1,00	0,81	0,88	0,94	374																
122		Production cart, usedy crop, EUR/ha	1,00	0,81	0,88	0,94																	
123		Output																					
124		Winter Wheat, grain, kg	-0,10	-0,10	-0,10	-0,10	4800																
125		Winter oilseed rape, kg	-0,21	-0,21	-0,21	-0,21																	
126		Sugar beets, t/ha	-6,03	-6,03	-6,03	-6,03																	
127		Sugar beet tap, t/ha	-0,04	-0,04	-0,04	-0,04																	
128		Graz, Scandinavian fodder unit	-0,12	-0,12	-0,12	-0,12																	
129		Straw, t/ha	-46,91	-47	-47	-47	3,2																
130		Willow chips EUR/ha	-1,00	-1,00	-1,00	-1,00																	
131		Wood chips, EUR/ha	-1,00	-1,00	-1,00	-1,00																	
132		Freight compensation	-0,61	-0,15	-0,31	-0,46																	
133		Energy balance																					
134		Input GJ/ha																					
135		Output GJ/ha																					
136		of which by products (e.g. straw) contribute, GJ																					
137		Net energy yield																					
138		Output/input																					
139		Cart price, Euro per ha, rconaria	P100				748	914	730	852	1606	897	358	597	116	213	1,000	P100	7,8	5,9	10,2	7,8	6,0
140		Cart price, Euro per ha, rconaria	P25				530	645	512	593	1234	637	275	461	91	165	1,000	P25	5,5	4,1	7,2	5,4	4,6
141		Cart price, Euro per ha, rconaria	P50				603	734	585	630	1358	724	302	506	99	181	1,000	P50	6,3	4,7	8,2	6,2	5,0
142		Cart price, Euro per ha, rconaria	P75				675	824	658	766	1482	811	330	552	108	197	1,000	P75	7,1	5,2	9,2	7,0	5,5
143		Area distribution 1000 ha, rconaria	P100				934	1081	111	0	46	247	0	5	300	300			2166				
144		Area distribution 1000 ha, rconaria	P25				654	764	44	0	42	549	0	5	300	300							

Solver Parameters

Set Target Cell:

Equal To: Max Min Value of:

By Changing Cells:

Subject to the Constraints:

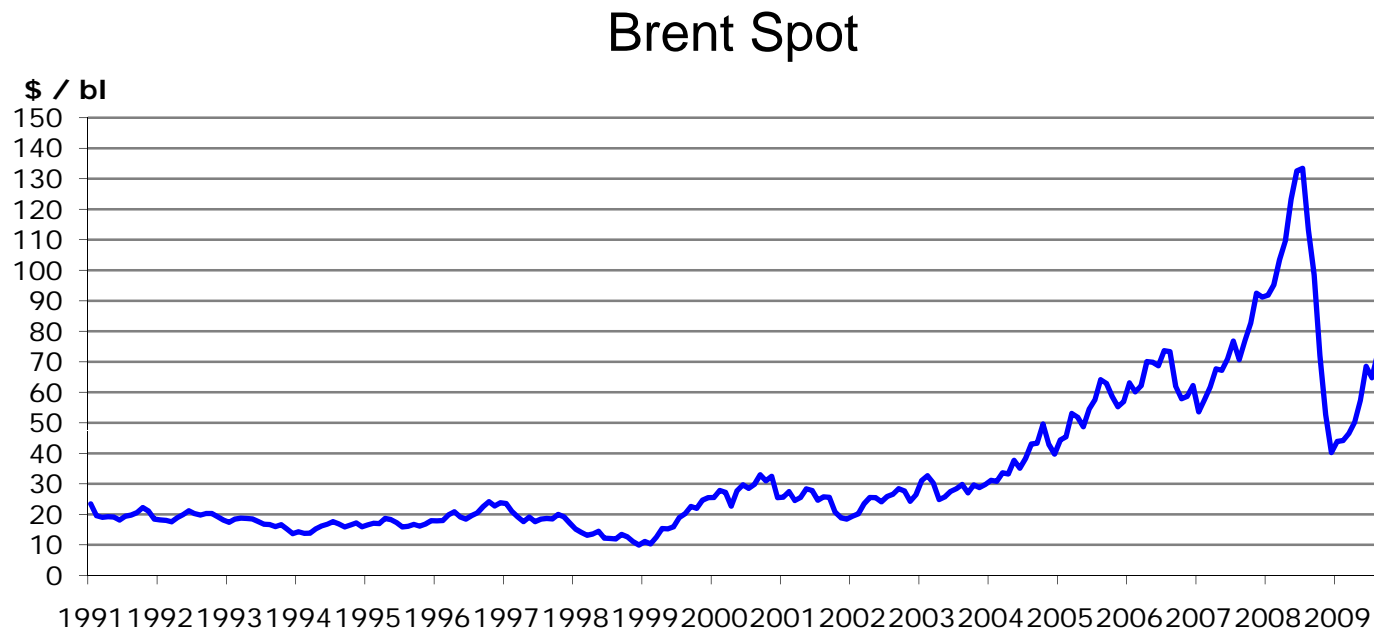
Model constraints I



- 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	18
Social	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

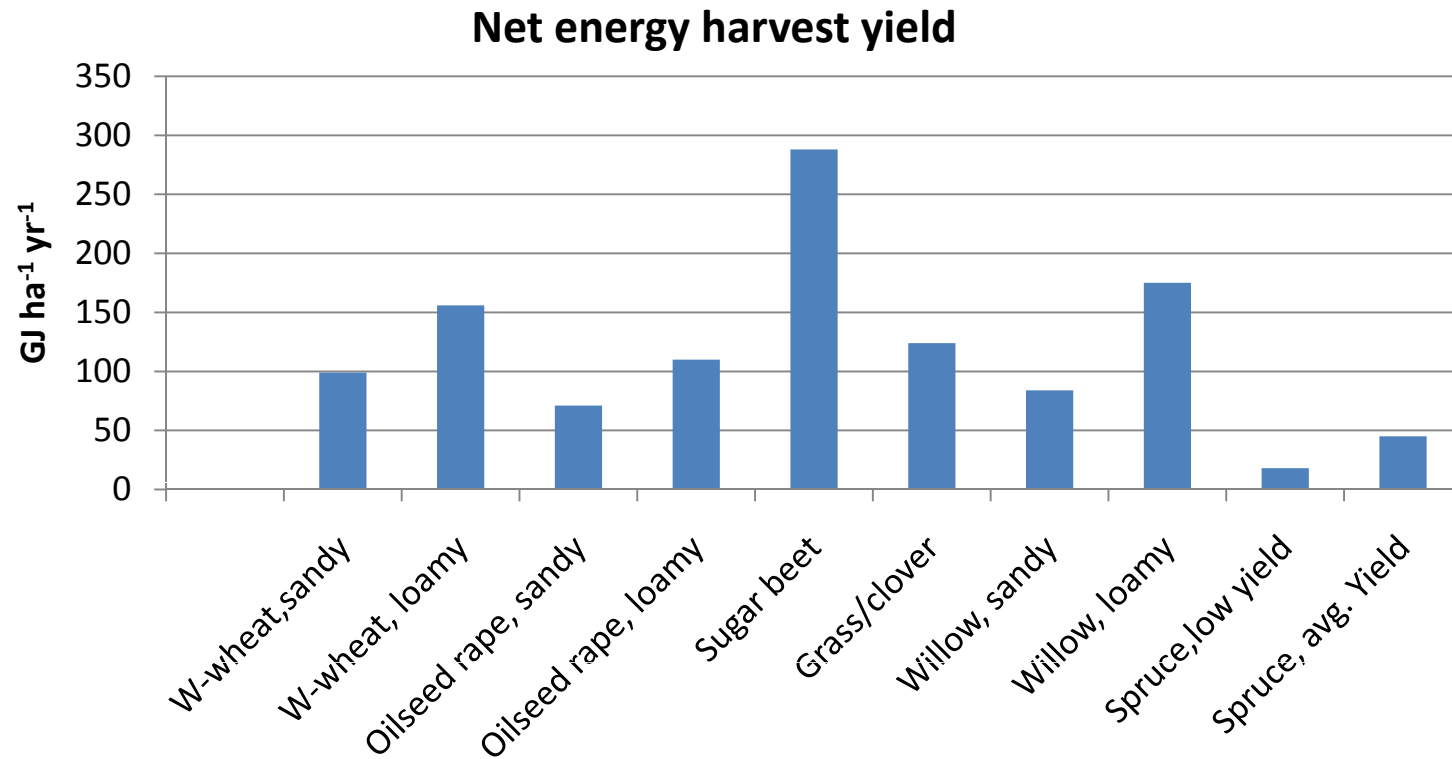
Scenario B

Food & feed
50% of scenario A

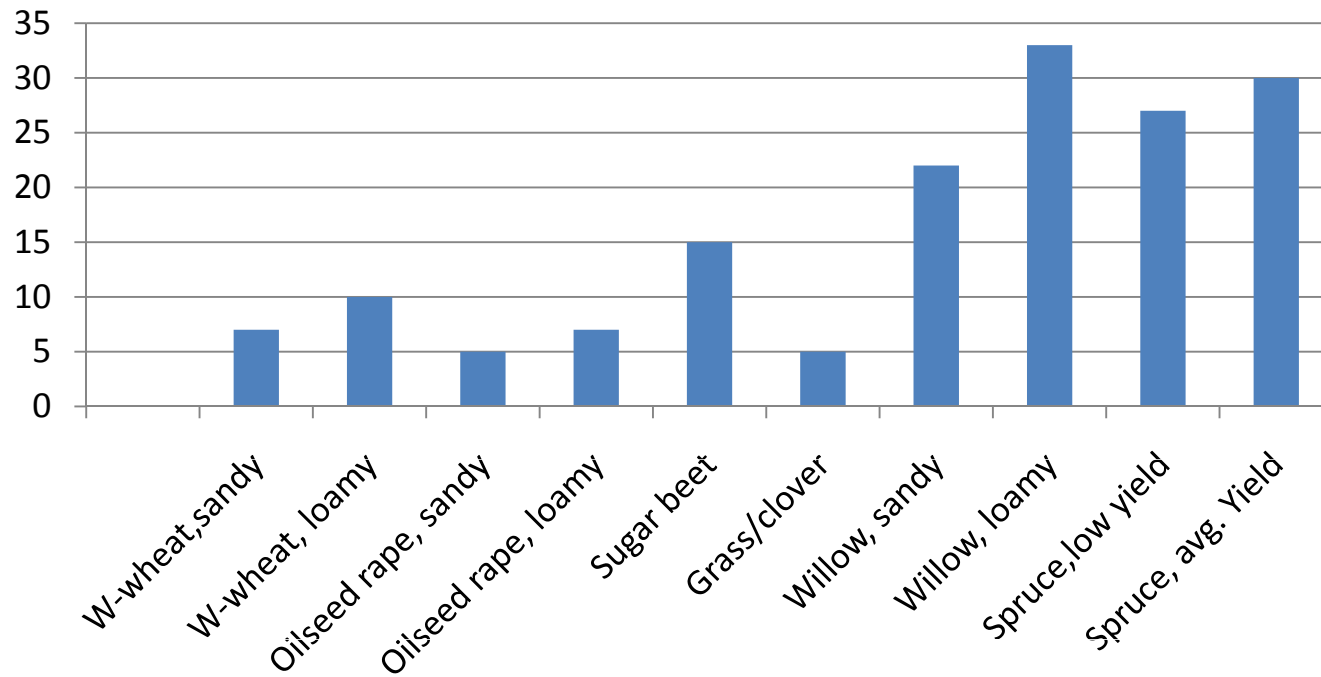
Willow < 25% area

Permanent grass
275 kha

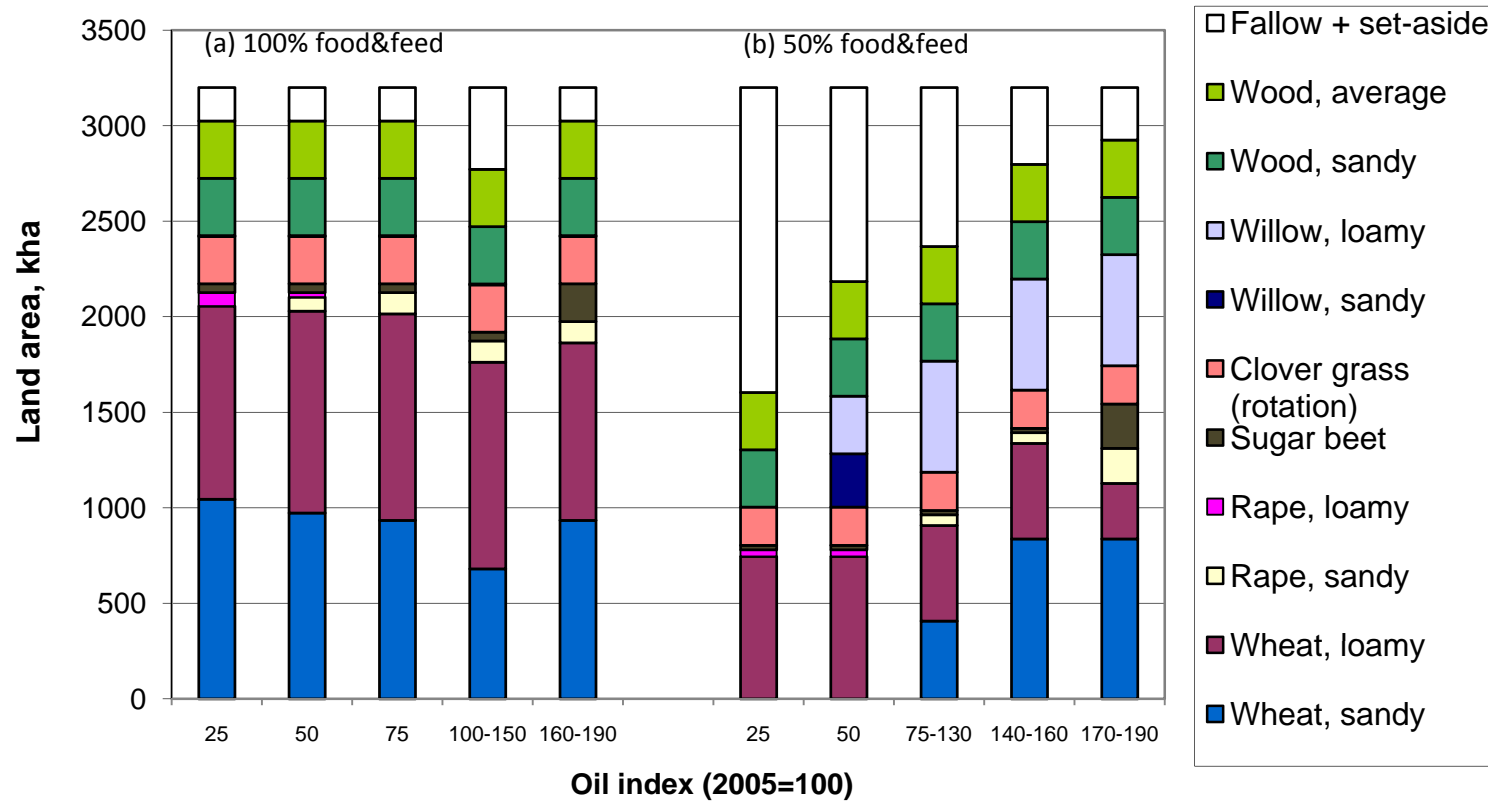
Crop yields



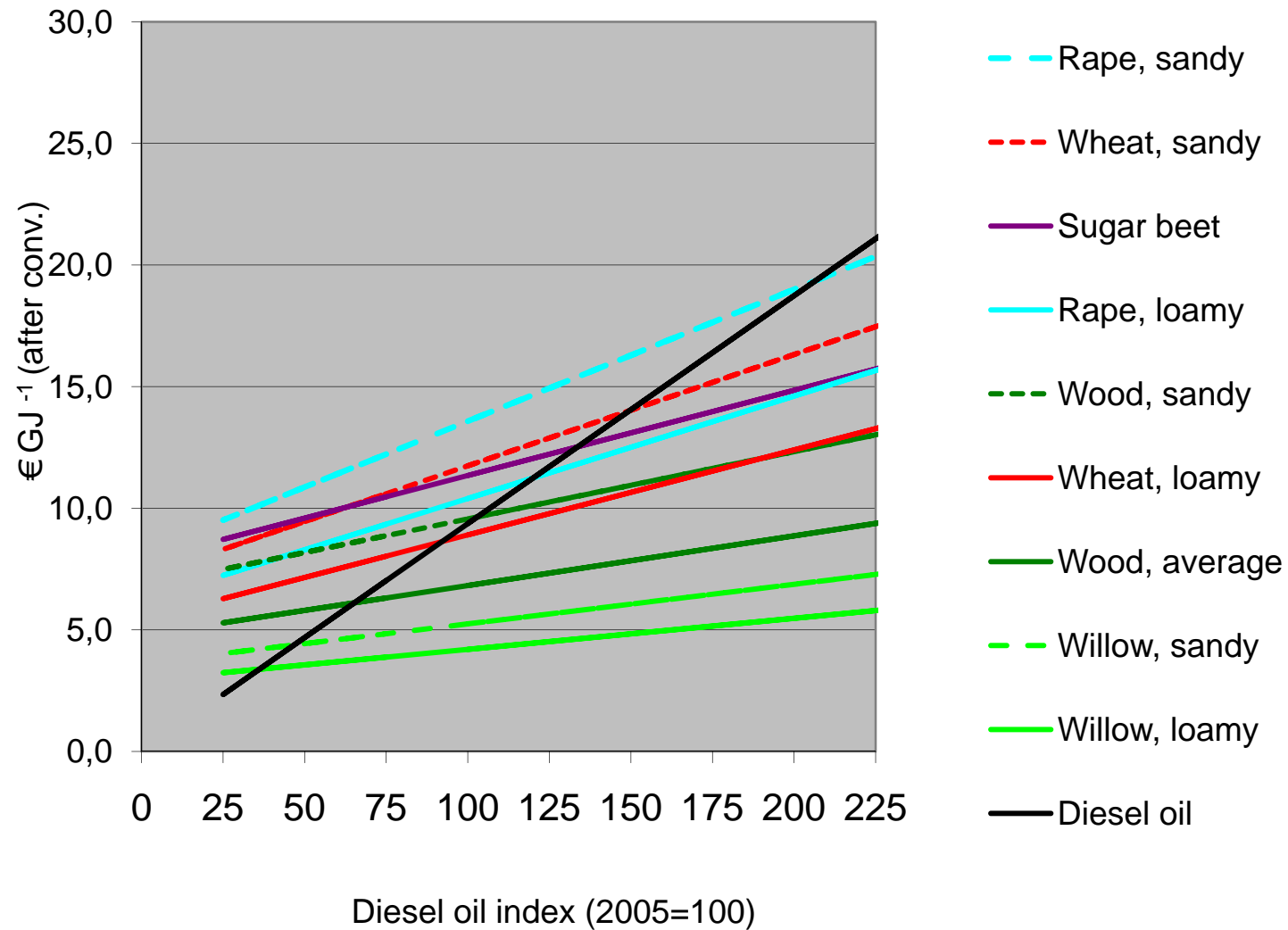
Energy output:input ratio



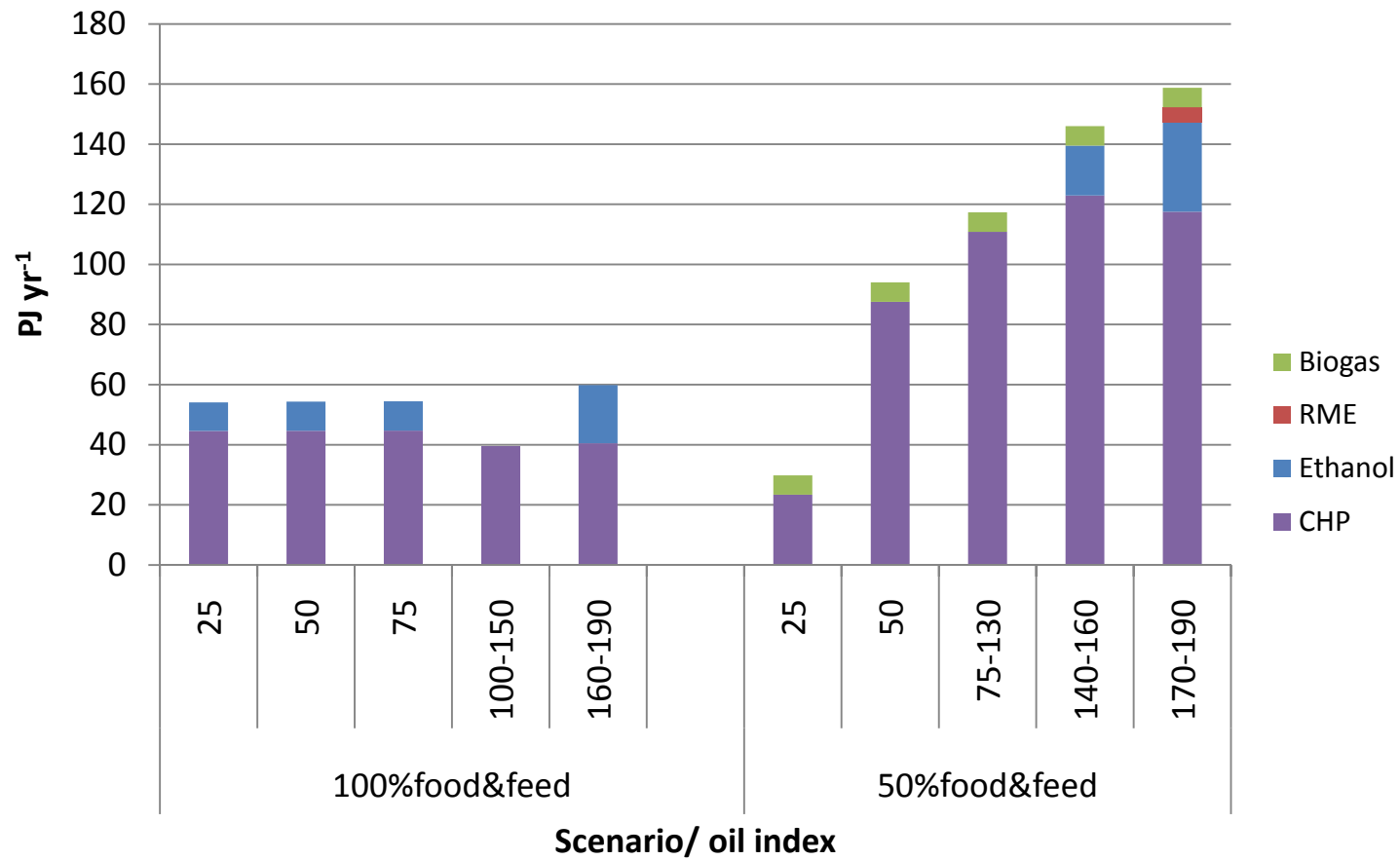
Crop area distribution



Biomass feedstock cost



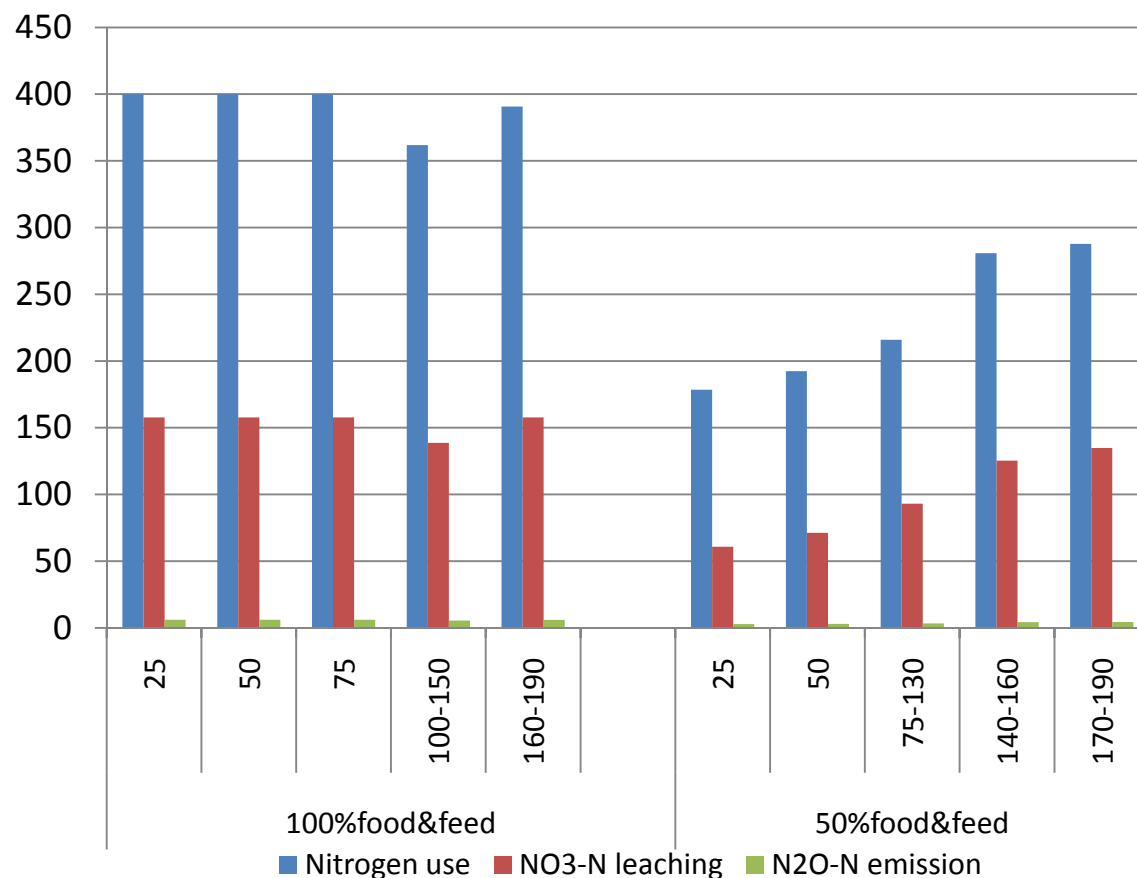
Bioenergy yield



Nitrogen load from cultivated land



- Reduction in N use and thus in N leaching and in N₂O losses



Bioenergy future scenarios

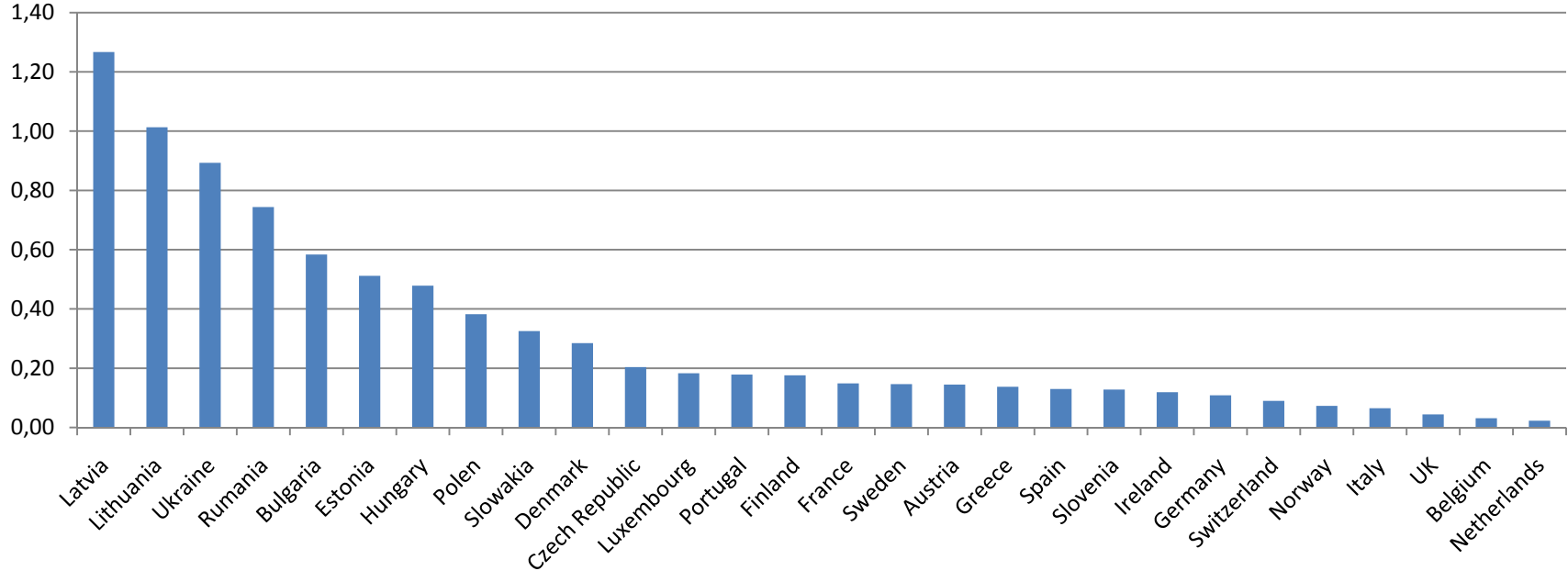


Jørgensen, 2008	AGR	FOR	WASTE	TOTAL
		PJ yr ⁻¹		
Current	5	25	19	50
Scenario	82	32	33	147
EEA, 2006	AGR	FOR	WASTE	TOTAL
2010	17	4	96	117
2030	4	8	92	105
Our study, Oil index 100	AGR	FOR	WASTE	TOTAL
100%FF	0	21	32	53
50%FF	6	125	18	149

Biomass in EU27



Potential self sufficiency (2030 supply vs 2005 consumption)



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



Available at www.sciencedirect.com



<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